FINAL REPORT

Sitka Sound Science Center

Collaborative Research with the Sitka Sound Science Center and the Geological Survey of Canada to Investigate Recent Deformation Along the Queen Charlotte-Fairweather Fault System in Canada and Alaska, USA

Reference: FY2015 EHP Program Grant G15AP00034

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February 2017

Abstract

This NEHRP study was designed to investigate the Queen Charlotte-Fairweather (QC-FW) fault system, which is the active transform boundary between the Pacific Plate and the North American Plate, using the Canadian Coast Guard Ship (CCGS) *John P. Tully* to collect geophysical data and seafloor photographs, core and grab samples. The primary objective of the study was to identify and map piercing points such as channels and gullies that could be used to estimate offset along faults of the Queen Charlotte (QC) fault zone and date fault movement using datable material within the collected piston cores to determine slip rates. To this end the cruise was extremely successful as we were able to identify at least four erosional features such as a canyon and three gullies that consistently exhibited approximately 800 m ±50 m offsets along the central segment of the QC fault zone. Using an age of 14.5 ±0.5 ka for the complete retreat of the last major glacial advance established by Barrie and Conway (1999) and the youngest dates of the sediments recovered in cores of the piercing points at approximately 17 ka, we estimate a slip rate of approximately 55 mm/yr, similar to slip rates calculated by Brothers et al. (2016) in the northern segment of the QC fault zone and close to the 55-60 mm/yr. relative plate motion reported by Prims et al. (1997) and Rohr et al. (2000). This suggests that most, if not all, of the relative plate motion is accommodated along the QC fault zone.

In addition, we discovered a significant new mud volcano located on the continental slope off of Dixon Entrance that exhibits a 700 m gas (methane?) plume rising from the 1,000 m deep volcano crest. This along with other discoveries of gas and fluid plumes concentrated along the QC fault zone suggest that the structure is a leaky transform fault, although the source of the fluids are unknown at this time. However, we speculate that the gas is methane as methanogenic chemosynthetic communities were observed in bottom photos collected and during the cruise and in biological samples recovered by a sediment grab sampler.

Introduction

The proposed investigation of the southern and central parts of the Queen Charlotte-Fairweather (QC-FW) transform fault system to determine fault geometry and activity using the Canadian Coast Guard Ship (*CCGS*) *John P. Tully* was initiated 16 September 2015 and successfully completed on 26 September 2015. A Knudson low power, 12 element, 3.5-kHz high-resolution Chirp seismic-reflection profiling system was used to identify potential piercing points, such as channels, and sampling sites. A large (0.75 cu m) IKU grab sampler and a Benthos piston corer were used to collect seafloor sediment and an underwater camera system was used to photograph the seafloor. Over 900-line-km of sub-bottom profiles, including 12- and 18-kHz echo-sounder data were collected. A total of 42 samples and camera drop stations were made where 33 cores and five grab samples were recovered and three camera transects were made; two cores came up empty. All cores were run through a Multi-Scan Core Logger (MSCL) where density, velocity, and magnetic susceptibility were measured. However, due to a power failure on the MSCL only density and magnetic susceptibility could be measured at sea for Survey Areas 2 through 4 by manually moving the core through the scanner. All cores were split, described in detail, and sub-sampled, and the grab samples to be examined and described, at the land-based sediment lab of the Geological Survey of Canada's Pacific Geoscience Center, Sidney BC. The split cores were again run through the MSCL in the shore lab to collect physical properties, including gamma ray density, magnetic susceptibility and high-resolution image data. Interpretation of the seismic-reflection data was inititated using both the Knudson Post Survey and the Kingdom Suite software packages.

Post-cruise data processing and analyses were undertaken from October 2015 through December 2016 with multiple meetings of the scientific participants of the cruise and presentation of results at four major scientific meetings. Analysis of data is continuing today and is being used in planning for additional cruises and data collection. Preparation of manuscripts for submittal to peer-review scientific publications are presently being drafted. Plans for future investigations and proposals for funding of these investigations have been written or are being written. The result of this investigation established a solid scientific foundation for future work and provides new data and hypotheses on the geohazards of a major tectonic plate boundary. In addition, public outreach of the cruise results has been accomplished through a press release that was used by newspapers and radio stations in Alaska to inform the public of our activity and an AGU EOS article was published to inform the scientific community of our progress.

Background

The QC-FW fault system is a major structural feature that extends from near the northern end of Vancouver Island, Canada to well into the bight of the Gulf of Alaska (Fig. 1). This system represents a major transform boundary that separates the Pacific Plate from the North American Plate, similar to the San Andreas (SAF) fault system of California (Atwater, 1970; Plafker et al., 1978). The length of the QC-FW fault system is 1,330 km, slightly longer than the SAF, with a reported width of 1-5 km and approximately 75% of the system located offshore (Carlson et al., 1985). In most locations the continuity of the

QC-FW is not well constrained, although it has been speculated that this is a fairly continuous transform system. However, segmentation of the fault zone and the presence of ancillary faults are basically unknown for most of the fault system's length.

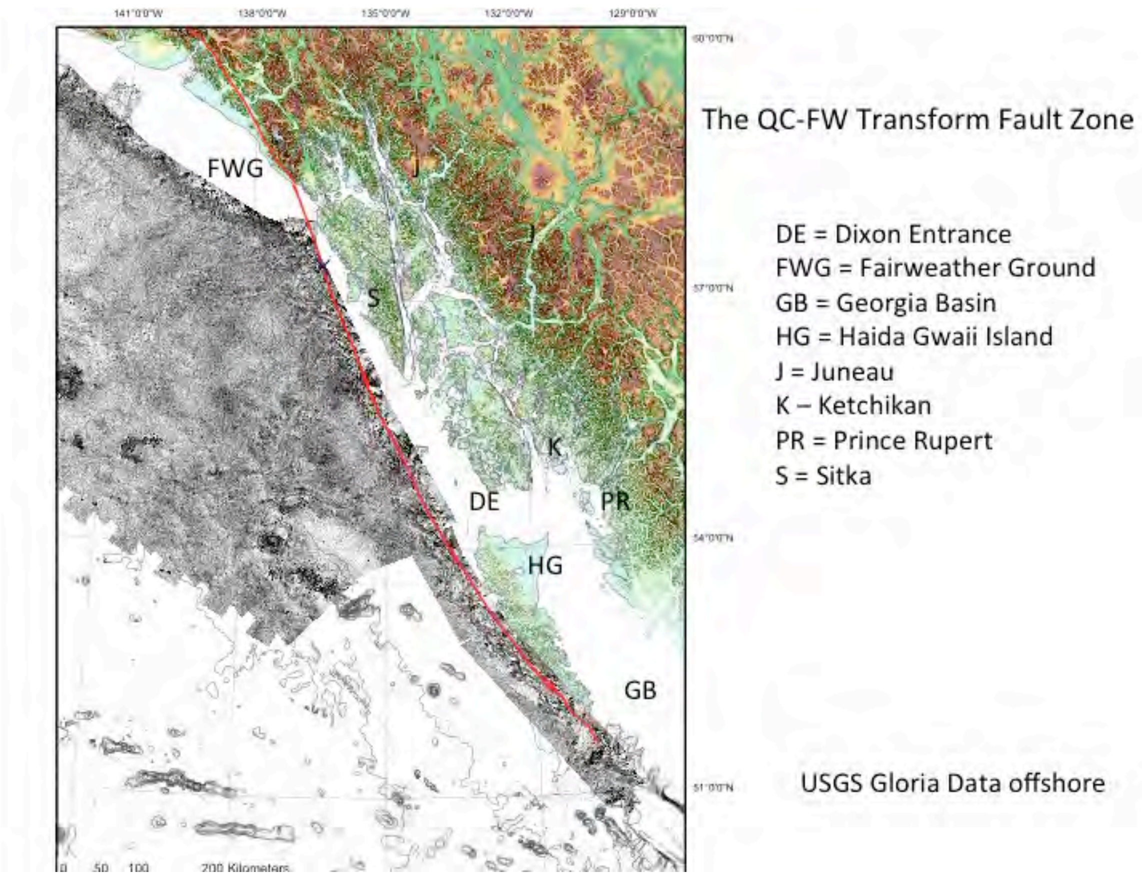

Figure 1. *The Queen Charlotte-Fairweather fault zone extending from onshore at the southern terminus of the Fairweather Range southward to the southern tip of Haida Gwaii Island. Courtesy of Daniel Brothers, USGS.*

In contrast, much is known of the SAF and other transforms throughout the world, primarily because a considerable amount of these systems are located on land and easily accessible. Therefore, to gain more knowledge about the geometry, rheology and kinematics of the QC-FW system marine geophysical and geological data were collected under this NEHRP project.

In the south the QC-FW fault system extends for over 350 km along the western margin of British Columbia and offshore of the Haida Gwaii Islands (formerly Queen Charlotte Islands) archipelago (Fig. 2). It is a near-vertical fault zone and seismically active down to approximately 21 km (Hyndman and Ellis, 1981) with a proposed mainly right-lateral transform motion of approximately 50-60 mm/yr. (Prims et al., 1997; Rohr et al., 2000). Here multibeam echosounder (MBES) data reveals evidence of a fault valley with small depressions on the upper slope, offshore central Haida Gwaii. The depressions form where strike-slip right-steps offsets have realigned the fault due to local slight oblique convergence (Barrie et al., 2013).

The 1949 M_S 8.1 (M_W 7.9) Queen Charlotte Island earthquake is the largest historical earthquake in Canada. This strike-slip event has an estimated rupture length between 265 and 490 km (300 km north and 190 km south of the epicenter) and an average co-seismic displacement of 4.0-7.5 m (Rogers, 1983; Bostwick, 1984; Lay et al., 2013). The 2013 M_W 7.5 Craig strike-slip earthquake occurred near the northern end of the 1949 rupture zone.

In contrast to the predominately strike-slip motion along the central and northern portions of the QC fault zone, plate motion along the southern portion is more oblique. The 2012 Haida Gwaii (M_W 7.8) earthquake involved slightly oblique thrust faulting on a shallow dipping fault plane whose strike is parallel to the QC fault zone (Lay et al., 2013).

In addition, several large earthquakes have been reported along the fault zone (Page, 1969; Carlson et al., 1985; Lisowski et al., 1987;) including the powerful (M_L 6.7) earthquake that occurred close to the QC-FW fault zone south of the Chatham Strait fault zone on June 28, 2004 (USGS, 2004), and the more recent 2012 Haida Gwaii (M 7.7) and the 2013 Craig (M 7.5) earthquakes occurred along the central and southern part of the fault system.

Additional recent seismicity includes a shallow (>1 km deep) moderate magnitude earthquake (M_L 5.7, January 6, 2000) along the QC-FW fault zone offshore of Yakutat and northwest of the entrance to Cross Sound (see Alaska Earthquake Information Center website, http://www.aeic.alaska.edu/html_docs/information_releases.html) and a deeper (10 km) moderate magnitude (M_L 5.9) that occurred in the south February 17, 2001 (http://www.aeic.alaska.edu/maps/southeast_panhandlemap.html), and the 2004 Chatham Strait (M_L 6.8) fault zone on June 28, 2004 (USGS, 2004; see Figure 3). Most recently, on 16 January 2017 a M 4.3 earthquake occurred on the QC fault offshore of Elfin Cove (offshore of Cross Sound), approximately 145 km north of Sitka, indicating the zone there to still be quite seismically active. Based on stress distribution, a continued rise in earthquake hazard for the Haida Gwaii, or central segment of the QC fault zone is anticipated (Bufe, 2005).

North of the Canadian border the QC-FW fault system is considerably wider than elsewhere to the south and may include the Chatham Strait and Peril Strait faults mapped along the fiords (Fig. 3). Here, various MBES seafloor images suggest that the QC-FW fault system may have numerous fault splays that partition slip along the system.

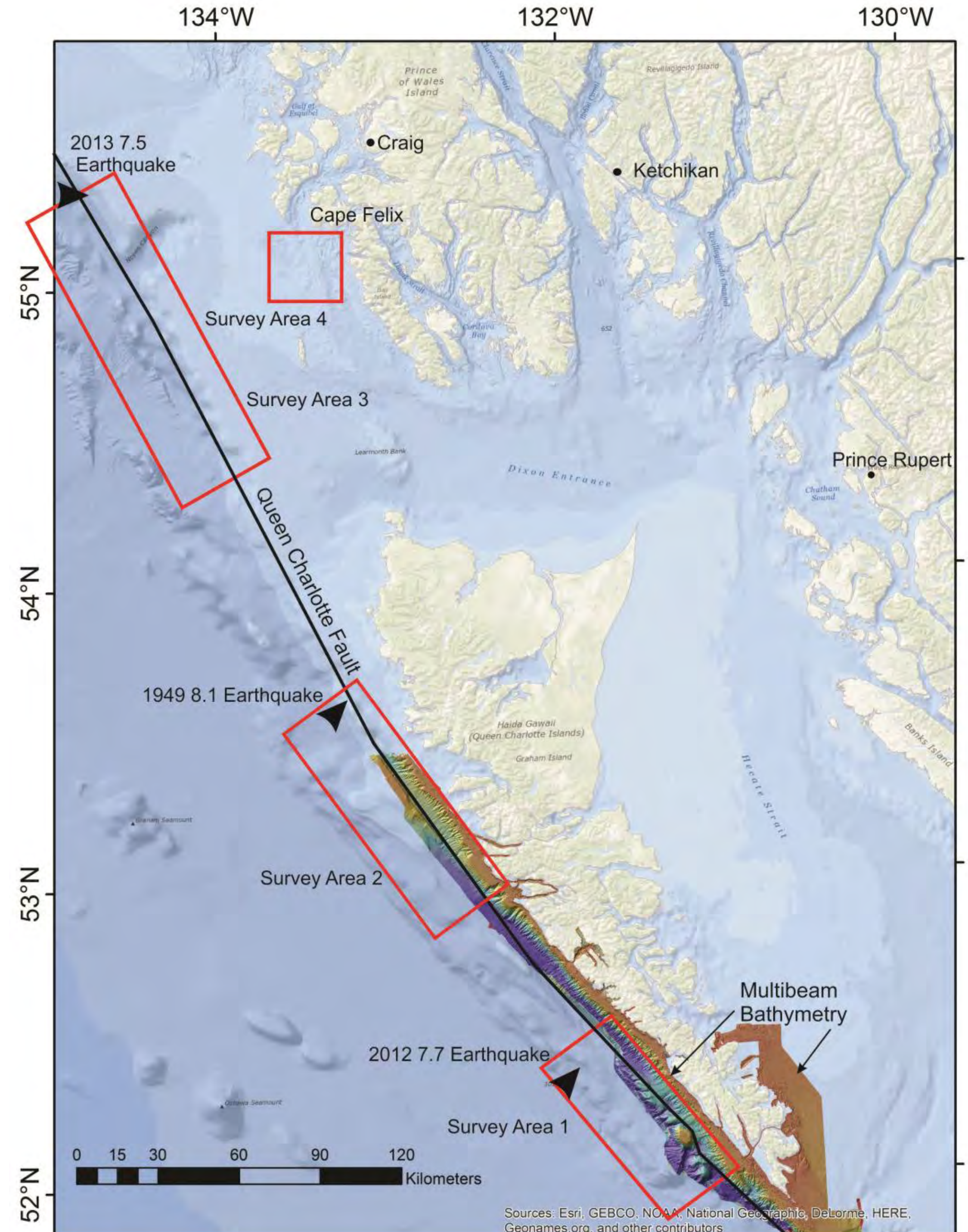

Figure 2. *Location map of the four survey areas showing MBES bathymetry coverage of the QC-FW fault system in the south within the Canadian EEZ and the location of less contiguous and non-MBES bathymetry in the north, within the Alaska EEZ.*

Therefore, our working hypothesis was that the central part of the QC-FW fault system is fragmented with many fault splays extending northeastward from the major north-south oriented fault zone upon which slip may have been partitioned and a significant amount of fault motion distributed towards the east and away from the accommodation zone located in the bight of the Gulf of Alaska. We investigated four specific sites, three where major earthquakes have occurred (the epicenter locations of the 1949 M_S 8.1, the Queen Charlotte, 2012 M 7.7 off Haida Gwaii, and the 2013 M 7.5 Craig earthquakes), as well as a nearshore area offshore of Cape Felix where multibeam bathymetric data shows faulted and sheared bedrock. In addition, an area of potential slumping offshore of Dixon Entrance was investigated in an attempt to determine slope stability and the potential for tsunami-generating landslides.

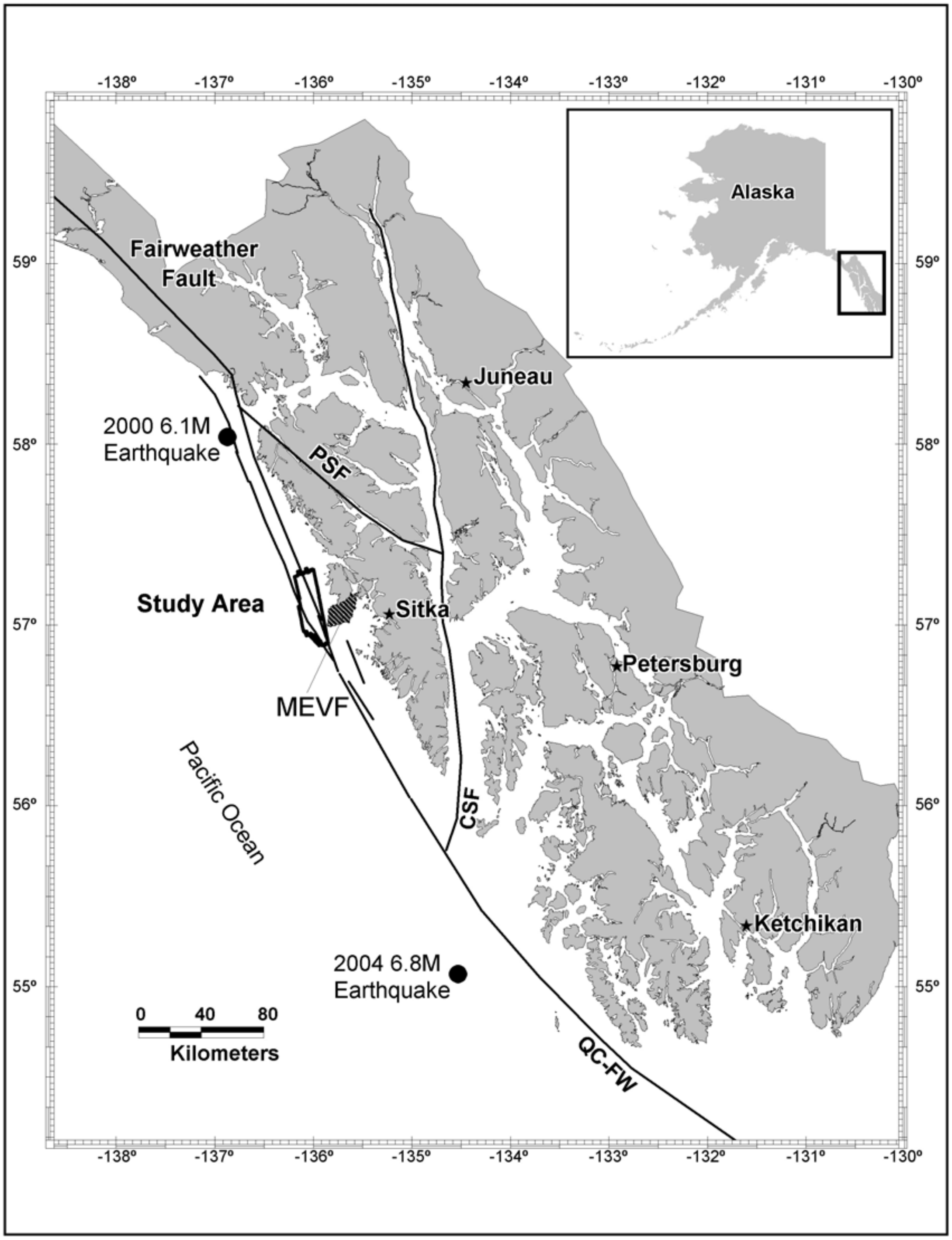

Figure 3. *An early map showing possible splay faults associated with the Queen Charlotte-Faiweather system and general locations of earthquakes recorded along the northern length of the Queen Charlotte-Fairweather fault system.*

Results

Results from the field work suggest that the QC-FW fault system is a knife-edge plate boundary between the Pacific and North American plates that accommodates most, if not all of the relative plate motion between the two plates. In addition, it appears that the fault system is characterized by leakiness, including fluids and gases that are emanating from fractures and faults that comprise the system. The northern segment of the system (referred to here as the northern segment of the QC fault zone), extending from the Fairweather Mountain Range in Alaska southward to where it connects with the formally named Queen Charlotte segment (called here the central segment of the QC fault zone north of Haida Gwaii Islands, has been characterized as a leaky transform fault with the Edgecumbe Volcano being an example of leakiness associated with magmatic processes (Brew, 1969; Reihle et al., 1992; Greene et al., 2007). At the southern end of the system, or southern segment of the QC fault zone (Fig. 4) two volcanic cones have been reported to have fluid plumes emanating from their crests (Barrie et al., 2013) and the discovery of another volcano-like feature emanating fluids from its crest in the central part of the system (central QC segment), offshore of Dixon Entrance, and a newly discovered fluid plume offshore of northwestern Haida Gwaii suggest that fluid leakage along the fault zone is fairly common. In addition to these fluid discoveries, a distinct canyon and many gullies that are offset offshore of central Haida Gwaii were imaged using the 3.5-kHz Chirp system and cored for dating material that could aid in constraining a fault slip rate estimate. And finally, the fault shear zone mapped offshore of Cape Felix was imaged using the 3.5-kHz system and cores were taken from ponded sediments within faulted bedrock troughs. We focused on four offshore areas that include Cape St. James off southwestern Haida Gwaii (Survey Area 1, Fig. 2), central Haida Gwaii, (Survey Area 2, Fig. 2), western Dixon Entrance-southern Alaska (Survey Area 3, Fig. 2), and Cape Felix (Survey Area 4, Fig. 2).

Survey Area 1 (Cape St. James)

Four sub-bottom profiles were collected along four NW-SE oriented tracklines that cross the fault zone and the associated gullied ridge to the east on September 18 (Fig. 4). The purposes of these crossings were: 1) to image the sub-bottom character of the fault zone, and 2) to obtain high-resolution bottom profiles that can be used to validate the reported 5+ m of seabed movement associated with the 2012 M 7.7 earthquake. Two additional 3.5 kHz seismic-reflection profiles were collected parallel to the fault zone to identify any potential piercing points that could be used to determine offset. Initial interpretation of the bathymetric and geophysical data indicates that a smeared bajada exists in the area west of the QC fault zone and that a well-defined, vertical fault scarp, with relief of approximately 45 m, exists with a submarine slide located at the base of the scarp that may have failed during past earthquakes. Unfortunately no piercing points were identified in the initial interpretation of the data. However, to date fault activity in the area, three piston cores were collected and scanned with the MSCL. Initial results are briefly described below:

Core 1 (Station 1)	A short (~108 cm) core collected in slide deposits at base of fault scarp shows possible slide material overlying pelagic deposits.

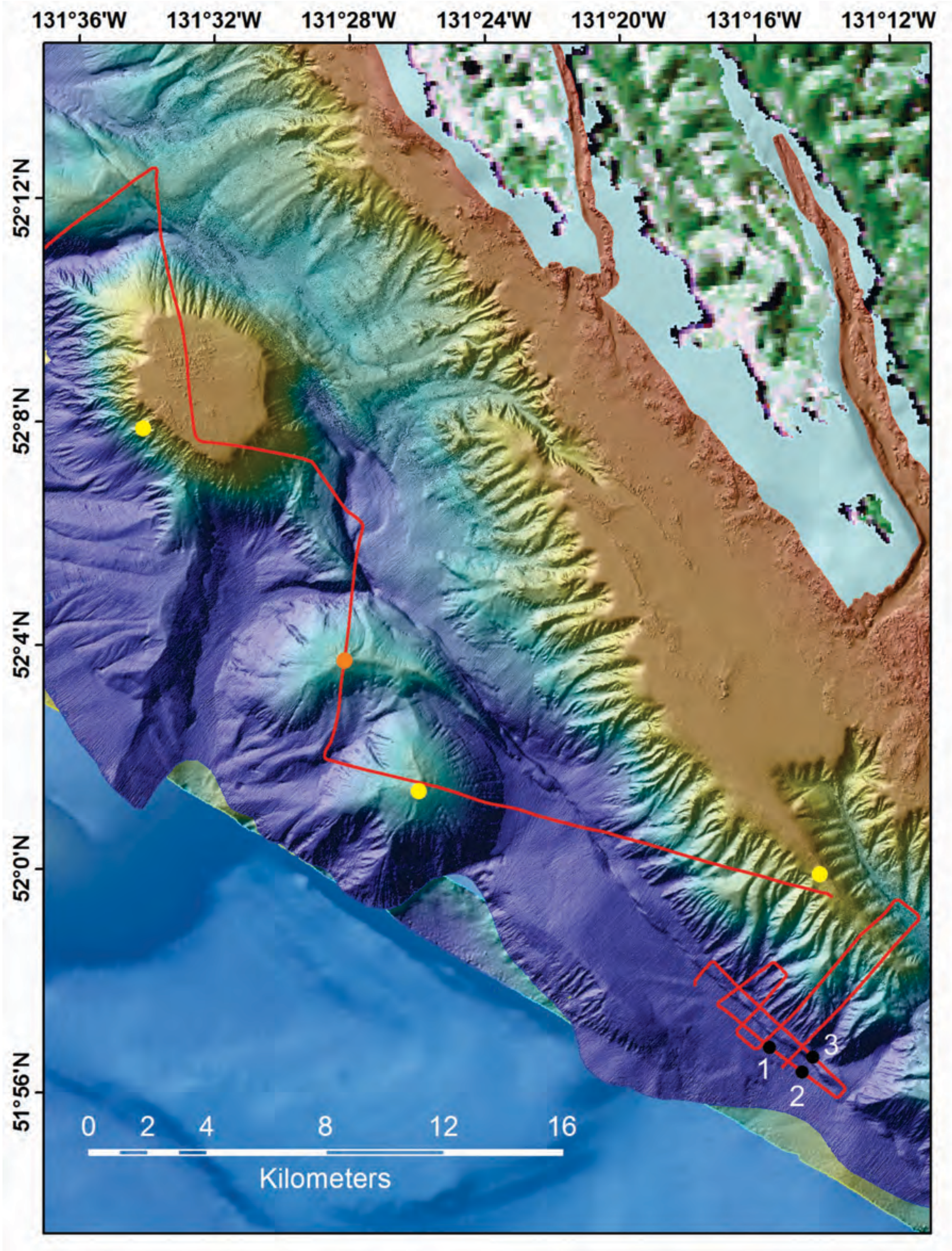

Figure 4. *An MBES bathymetric image of Cape St. James, Southwestern Haida Gwaii Islands (Survey Area 1) with 3.5-kHz tracklines in red, the recently (2012) ruptured length of the fault and two volcanic cones crossed during the survey. Source: Canadian Hydrographic Service - Pacific. Yellow dots represent previously identified plumes and*

the orange dot is previous identified plume that was also observed during this study. Black dots are piston core locations, and white numbers represent Station numbers.

Core 2 (Station 2). A short (~2 m) core collected in thalweg of a channel contained sand and gravel.

Core 3 (Station 3). A short (~2 m) core collected in the eastern part of the bajada east of the fault scarp contained interbedded fine to coarse sands similar to a turbidite.

Transit from Survey Area 1 to Survey Area 2

During the transit on September 18-19 from Survey Area 1 to Survey Area 2 a zigzag line was run where 3.5-kHz sub-bottom profiles were collected (Fig. 4). These lines were designed to cross over the crests of two coalescing volcanic-like cones that previously had been seen with gas plumes rising above their crests, and across an unusual circular flat-topped bank. The line across the most southerly cone missed the crest and a plume was not observed, but the second line that crossed the northern cone's crest did image a plume with the 18-kHz sounder. The surfaces of the cones and bank are hard and little or no sub-bottom penetration was obtained in the 3.5-kHz profiles.

Survey Area 2 (Central Haida Gwaii)

The surface expression of the QC fault zone is well imaged offshore of central western Haida Gwaii Islands (Fig. 5). Here one of the larger submarine canyons along the western margin of Haida Gwaii heads at the shelf break, and informally named here "Cartwright Canyon". This canyon has two major heads, tentatively named here "Skidegate" and "Buck". Another multi-gullied head is located to the north of the two major heads and connects by a single channel to the lower part of Cartwright canyon, about half way down the slope from the shelf break to the fault zone.

Two full days (September 19-21) were spent in this survey area with coring undertaken during the day and 3.5-kHz sub-bottom profiling data collected during the night. On the first day in the survey area we ran a few 3.5-kHz profile lines perpendicular and parallel to the surface expression of the fault zone. An approximate 800 m right-lateral offset occurs in the lower part of Cartwright canyon where it intersects the fault zone.

Gullies on the slope east of the fault zone are all truncated along faults (Fig. 5). The gullies that lie south of the wide, flat channel opening to a fault rift valley, here tentatively called the "Rift Opening", which extends northward along the fault zone, appear to be offset along a smeared bajada, or talus fans of Harris et al. (2014). Channels south of Cartwright canyon appear to be fluid induced as they exhibit rilling, retrogressive slumping, and slump movement down gully, similar to what has been described in Santa Barbara Channel and in the Monterey Bay region (Eichhubul et al., 2001; Greene et al., 2002). One crossing just up slope of a channel mouth near the fault

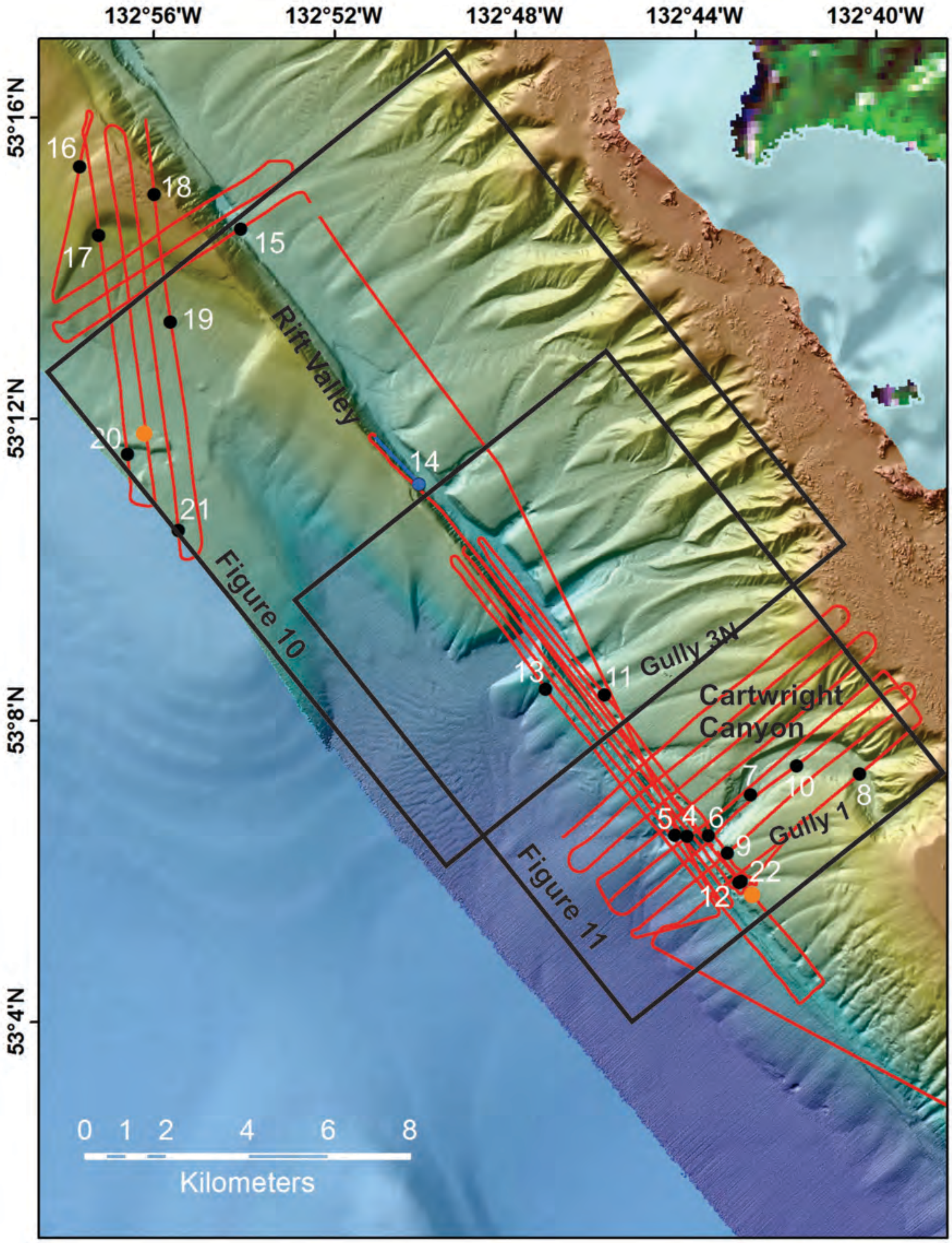

Figure 5. *MBES bathymetric image of Survey Area 2. Location of offset seafloor channels where lower Cartwright Canyon (Shown with two heads, Skidegate and Buck heads in lower SE corner of image) appears offset to the right by the QC fault zone. Red lines are 3.5-kHz tracklines, orange dots are newly identified plumes, black dots are core locations, blue dot/line are photo transects, and white numbers represent Station*

numbers, black line boxes show location of Figures 10 and 11. Source: Canadian Hydrographic Service - Pacific.

zone and just south of Cartwright canyon showed a fluid plume in the 18-kHz profile indicating that fluid flow is present in this area.

To the north of the "Rift opening" a high bedrock ridge that tapers downward toward the south to the Rift opening blocks sediment transport to the east and directs it southward (Fig. 5). Here the rift valley is filling and acts as a sediment conduit. A large landslide has excavated a substantial part of this ridge, which was one focus of our coring campaign, in that the landslide may reflect the timing of a major earthquake along this section of the fault zone. Preliminary descriptions of the cores are provided below:

Core 4 (Station 4).	The first core taken at this survey site was located in what appears to be a sill between the eastern main channel of Cartwright canyon and the western offset channel. A very short core was recovered with the core-catcher containing gravel and fragments of volcanic rock.
Core 5 (Station 5).	A second, very short core was collected in the western offset channel of Cartwright canyon, near the fault and containing gravels at the bottom and mud on top.
Core 6 (Station 6).	The third core was collected in lower Cartwright canyon, in a flat area closest to, and east of the fault zone, and below the scarp of a retrogressive slump. Again, this core was very short with hard dense sand and mud.
Core 7 (Station 7).	The fourth core collected in this survey area was located in the middle part of Cartwright canyon, in the lower part of the meander above the upper retrogressive slump. Recovered a very short core with sand above mud.
Core 8 (Station 8).	The fifth core collected was located above the meander in upper Cartwright canyon near the mouth of the northern Skidgate head, and was short containing dense sand.

The 3.5-kHz profiling survey continued during the night of September 19th to complete the proposed lines across the fault, parallel to the fault, and over the landslide in the north. During this survey the gas plume at the mouth of a gully just south of Cartwright canyon and another gas plume near the base of the landslide were imaged in the 18-kHz sounder profiles. These areas became targets for coring and drop camera transects.

During the day of September 20th an extensive core sampling and bottom photography campaign was undertaken. Cores recovered are detailed below:

Core 9 (Station 9). The first core taken this day was located in the upper reaches of a gully (informally called gully 1) where a short core of sand over mud was collected, however the sand could have been sucked into the corer during pull-out.

Core 10 (Station 10). A second core was taken from the inner levee of Cartwright canyon, within the meander, and contained little sand, but little else due to a poor recovery.

Core 11 (Station 11). A third core of the day was collected near a landslide head scarp within the mouth of a third major gully (informally called gully 3N) north of Cartwright canyon and the surface expression of the fault zone. Poor recovery occurred here with only stiff mud obtained in core catcher.

Core 12 (Station 12). The fourth core of the day was collected at the confluence of two gullies just south of Cartwright canyon, which contained a short hard clay core.

Core 13 (Station 13). This was the fifth core of the day and located in the first gully south of the Rift opening on the west side of the fault zone, but nothing was recovered.

Camera Tow 1 (Station 14). This camera tow was made along the most recent seafloor rupture of the QC fault zone in the Rift valley. Photos show much sand and gravel cover over mud with conglomerate and angular, fragmented blocks of mud (Photo 1). Evidence in the form of possible *Calyptogena* clam shells, some appearing in the living position, and carbonate-like slabs in the vicinity of where a gas plume was observed previously indicates fluid flow.

We continued to survey during the night of September 20th in a large slide area west of the Rift valley and north of the Rift opening using the 3.5-kHz system. Two gas plumes were discovered in the 18-kHz sounder profiles, one at base of large slide and another along a fault-parallel line in a gully just south of Cartwright canyon.

During the day eight core stations were occupied in an attempt to collect good stratigraphic piston cores. Preliminary examinations of these cores are given below:

Core 14 (Station 15). The first core of this day was located in a pull-apart basin within the Rift valley and recovered only a short core of sand.

Core 15 (Station 16). The second core in this area was located on the west-facing slope north of the head of the large landslide, within a subtle gully just north of the slide. Although this core was longer than the previous core it was still short and recovered sand overlying mud.

Photo 1. *Angular clay blocks and shell fragments from possible chemosynthetic communities associated with the QC fault zone at Station 14 in Survey Area 2.*

Core 16 (Station 17). A third core of the day was collected at the base of the northern slump headwall, in a slump deposit. The corer recovered a thin layer of unconsolidated sand overlying stiff clay.

Core 17 (Station 18). The fourth core of the day was recovered from a location above the head scarp of the slide, south of a pockmark field, in an area where the possible slide plane may be exposed or covered with a thin layer of unconsolidated sediment. No core was recovered, but very stiff clay was found in the core catcher and the pilot core recovered chunky dark clay overlying lighter less dense clay.

Core 18 (Station 19). The fifth core of the day was located at the base of a gullied slump apron, possibly a landslide plane. The recovered core was comprised of a thin layer of sand overlying about a meter of stiff clay.

Core 19 (Station 20). The sixth core of the day was located at the leading edge of a glide block in the lower part of the landslide near where a gas plume was discovered. Here the core recovery consisted of ~1 m of brown clay over gray clay.

Core 20 (Station 21). The seventh core of the day was located at the distal edge of the slide mass where a thin layer of fine sand overlying clay was recovered.

Core 21 (Station 22). The eighth core of the day was located just outside of the slide, but with no recovery.

The night time 3.5 kHz sub-bottom profiling survey was undertaken in the northern part of Survey Area 2, in an area sparsely covered by MBES bathymetric data and the location of the epicenter of the 1949 M 8.1 earthquake (Fig. 6). Coring continued during the day of September 22; the initial description of cores collected given below:

Core 22 (Station 23). The first core of the day was located on a linear terrace where it intersects the slope NE of a pull-apart basin, an area where the fault zone steps to the right, possibly changing from transtension to transpression (a right-steeping fault). Core recovery was short and consisted of a thin layer of sand over stiff clay.

Core 23 (Station 24). The second core was located north of the pull-apart basin, on the southern flank of what appears to be a transpressional ridge north of the MBES coverage. No sediment was recovered and only sand was found in the core catcher.

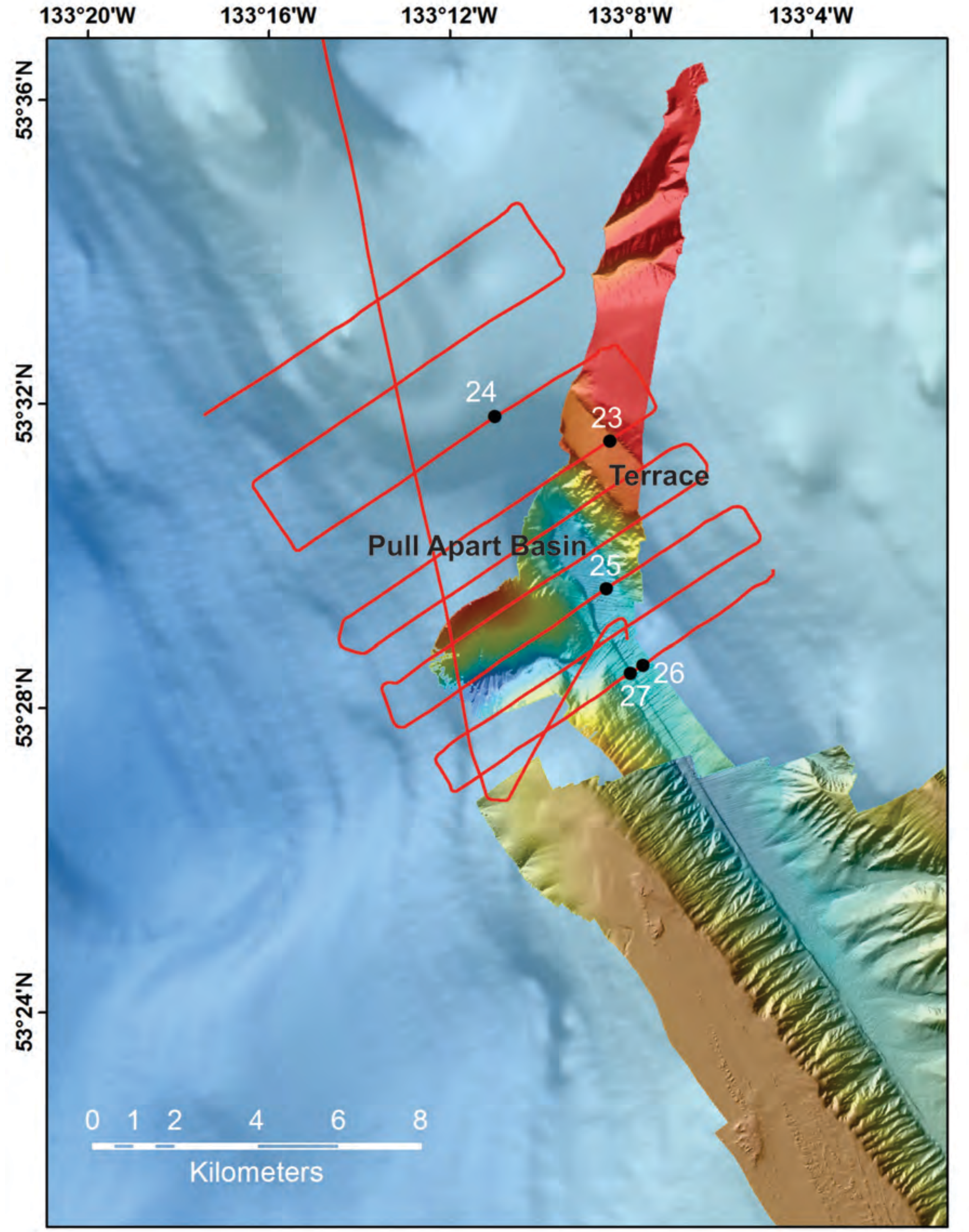

Figure 6. *Northern Survey Area 2 (Northern Haida Gwaii) with limited MBES bathymetric data. The 3.5-kHz profile lines shown in red crossing a pull-apart basin associated with the QC-FW faults system; black dots represent core locations and white numbers are Station numbers. Source: Canadian Hydrographic Service - Pacific.*

Core 24 (Station 25). A third core for the day was located on the floor of the pull-apart basin. A short core consisting of unconsolidated silty-sand overlying clay was recovered.

Core 25 (Station 26). The fourth core of the day was taken from a slump located on the west side of the pull-apart basin and consisted of a short core of sand overlying clay.

Core 26 (Station 27). The fifth core was taken from a slump located on the east side of the pull-apart basin. Here a short core with sand overlying clay was recovered.

Transit from Survey Area 2 to Survey Area 3

Completed coring program at northern part of Survey Area 2 and transited to Survey Area 3 during the night. Collected 3.5-kHz and other sounder data during transect and in survey area (Fig. 7). Switched to coring mode the morning of September 23rd. During the night's survey of Survey Area 3 located on the slope west of Dixon Entrance a previously unknown volcanic-like cone was observed to have an approximate 700 m high gas plume rising from its 1,000 m deep crest. We investigated the volcano in more detail after the completing the coring operations. The following are preliminary descriptions of cores taken at targets selected from interpretation of 3.5-kHz sub-bottom profiles:

Core 27 (Station 28). First core of the day was collected from a slump deposit near the upper head scarp of a large landslide on the slope west of Dixon Entrance. A short core was recovered, consisting of a sand layer overlying clay.

Core 28 (Station 29). Second core of day was located in a sediment pond of a possible conjugate or horsetail splay fault depression of the QC-FW fault system. A short core was recovered consisting of a thin sand layer overlying p-gravel.

Core 29 (Station 30). Third core of day was located in a sediment pond of the main trace of the QC fault zone. A short core was recovered consisting of silty-mud.

At mid-day shifted to 3.5-kHz survey of volcanic-like cone. A star-shaped pattern was run over the cone to collect both 3.5 and 18-kHz acoustic data to image the feature in better detail and to select camera transects and sampling sites. The 18-kHz profile showed that two plumes were rising from a crater-like depression in the crest of the cone (Fig. 8). A camera transect across the crest of the cone and its lower flank was undertaken and results of that work are described below along with the descriptions of collected IKU sediment samples obtained during the day of September 24:

Camera Tow 2 (Station 31). Excellent photographs were obtained during this camera tow, which indicated that methane gas was emanating from the cone. Evidence of methane is given by the presence of chemosynthetic communities consisting of *Calyptogena* spp. clams (Photo 2), a *Vestimentiferan* spp., tubeworm (Photo 3), *Beggiatoa* spp. bacterial mats (Photo 4), and carbonate slabs. No lava or outcrops of volcanic rock were photographed. In contrast gravel, pebbles and cobbles covering a mud slope were observed with much of the clasts being rounded. However, angular fragments of dark-colored rock were seen in the photos. Small narrow rivulets of mud were also observed (Photo 5).

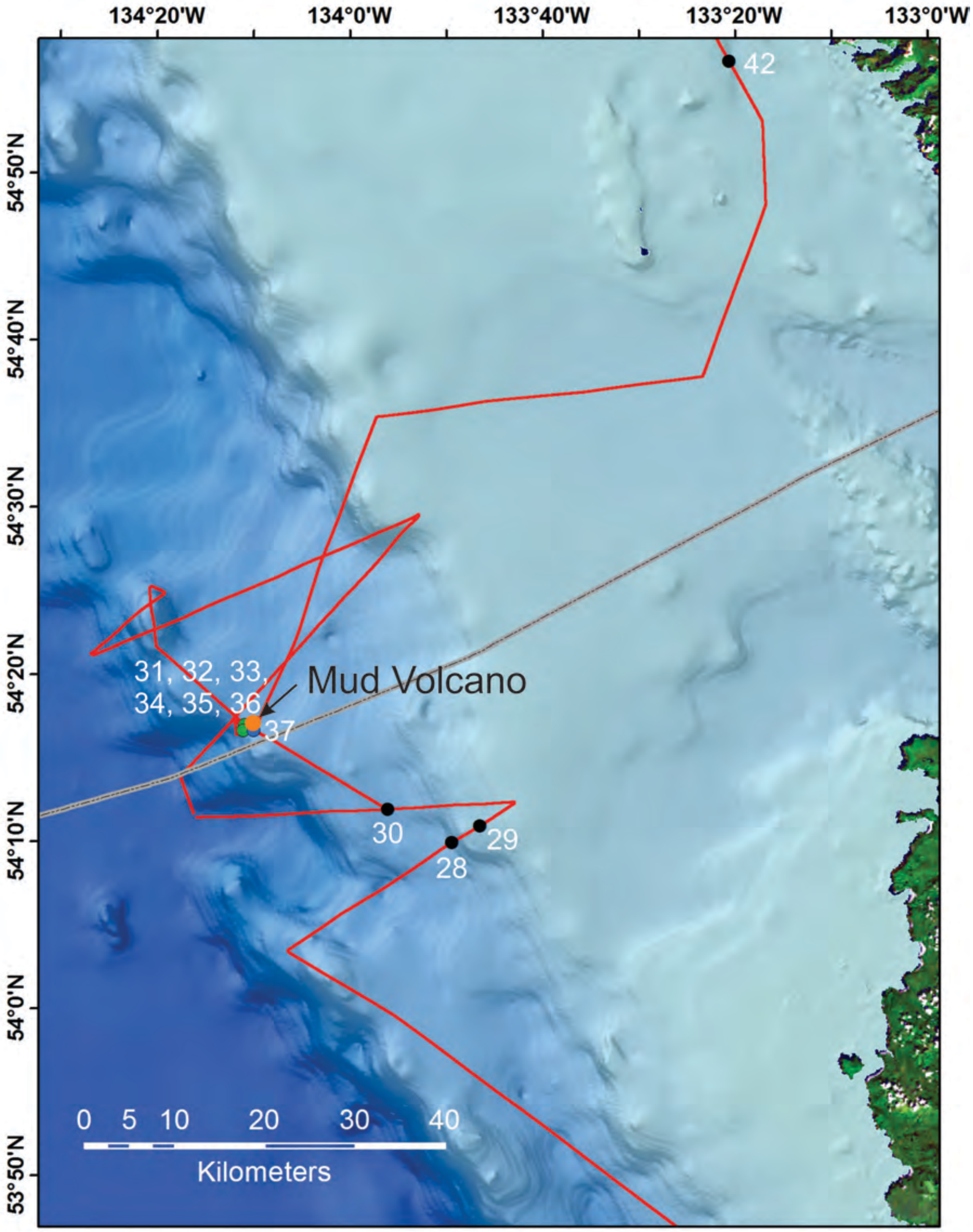

Figure 7. *Survey Area 3 on the slope west of Dixon Entrance. Only low-resolutionl bathymetric data exists for this area and the shaded relief imagery shown is based on a single-channel echo soundings. The existing imagery suggests an irregular seafloor possibly composed of slumps and cone-like structures. Red solid lines are 3.5-kHz sub-bottom profile transects and gray line is the approximate location of the US-Canada border. Black dots represent piston core locations, green dots represent IKU benthic*

grab sample locations, and blue shows the positions of the bottom camera transects as well as the location of a newly identified plume, and white numbers represent Station numbers. Source: Canadian Hydrographic Service regional data.

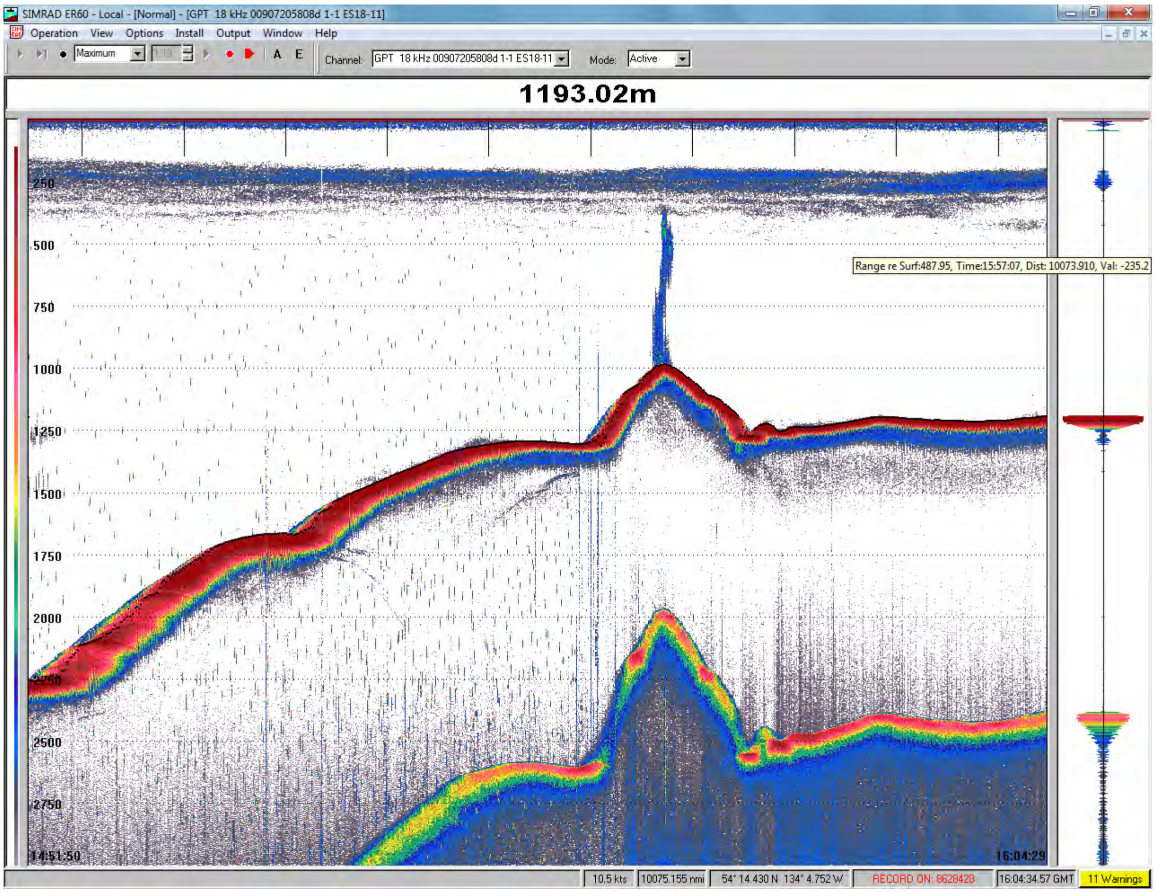

Figure 8. *An 18-kHz sounder profile of newly discovered mud volcano in 1,000 m of water with a 700 m plume on the continental slope just west of Dixon Entrance (see orange dot on* Figure 7 *for location of volcano's crest and source of gas plume.*

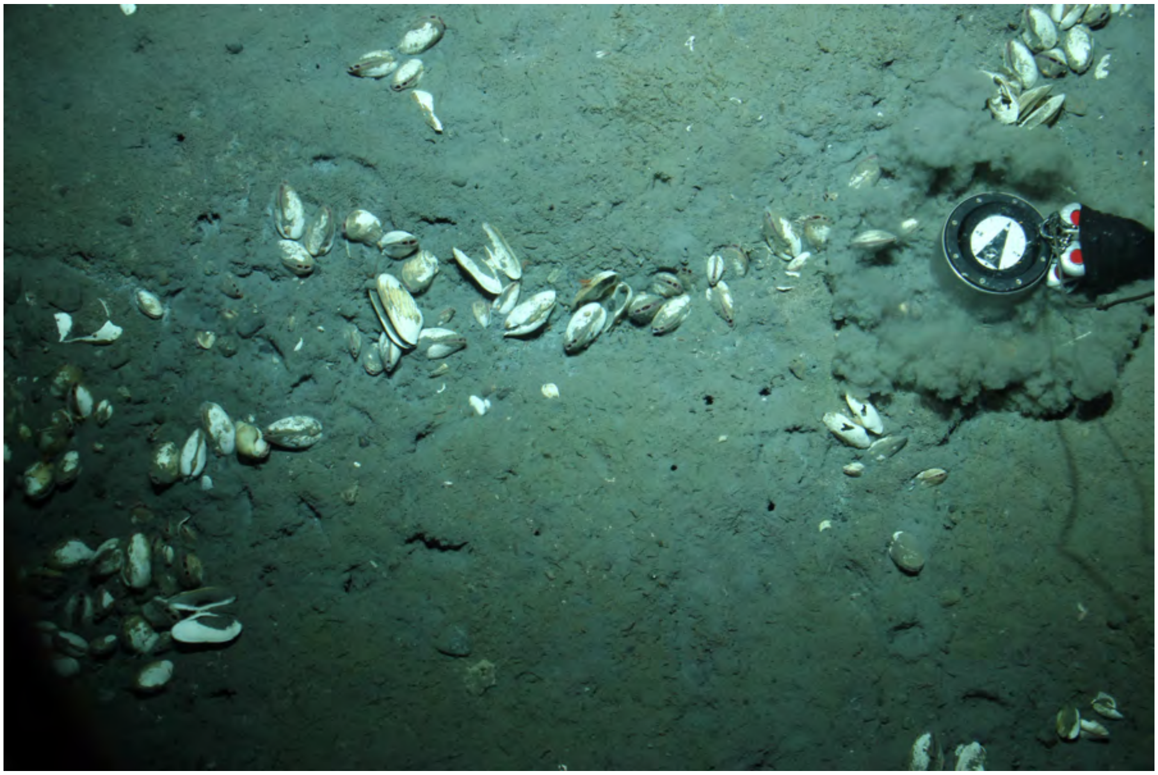

Photo 2. *Evidence of probable methane seeps at newly discovered mud volcano shown by* Calyptogena *clams (Photo P254, Survey Area 3).*

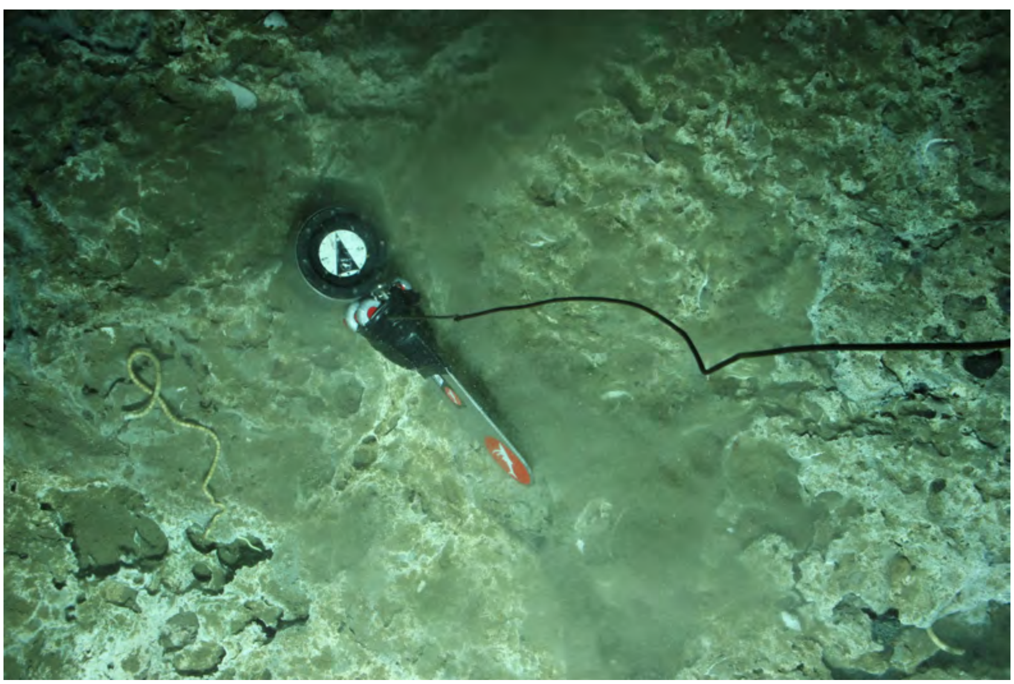

Photo 3. *Possible* Vestimentiferan *worm located near venting gas plume of newly discovered mud volcano (Photo P143, Survey Area 3).*

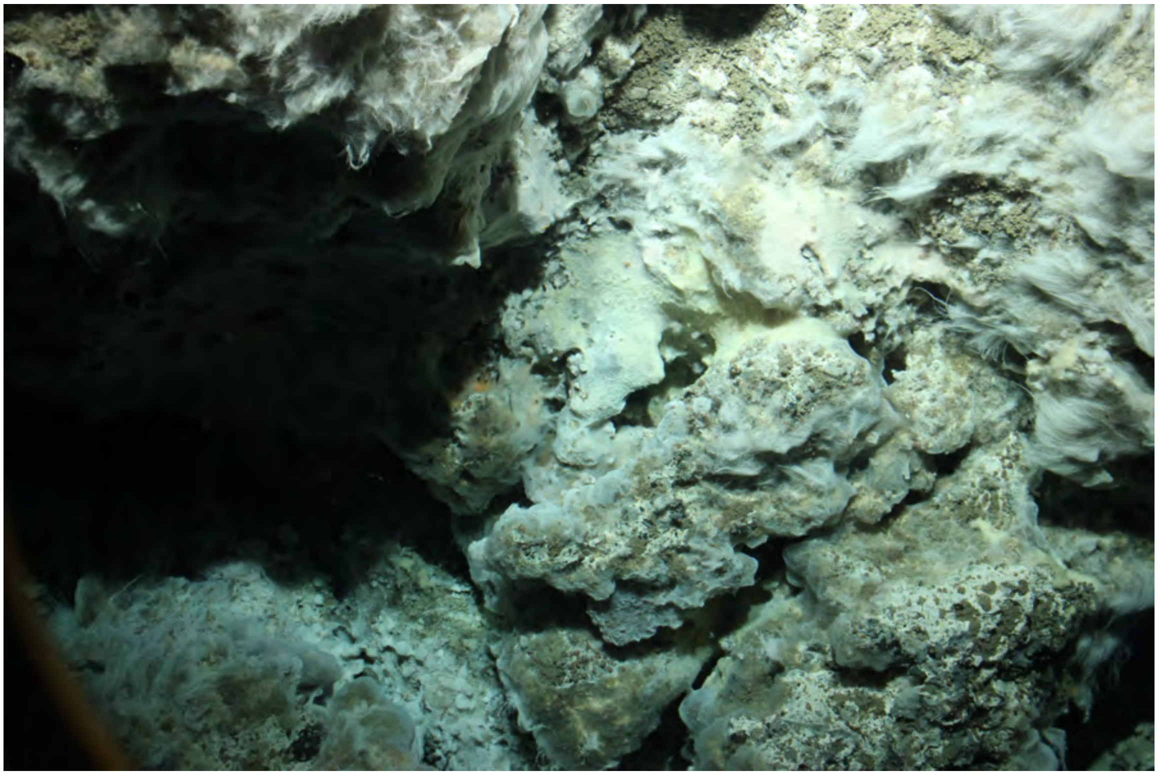

Photo 4. Beggiatoa*(?) bacterial mats and carbonate deposits at vent of newly discovered mud volcano (Photo P152, Survey Area 3).*

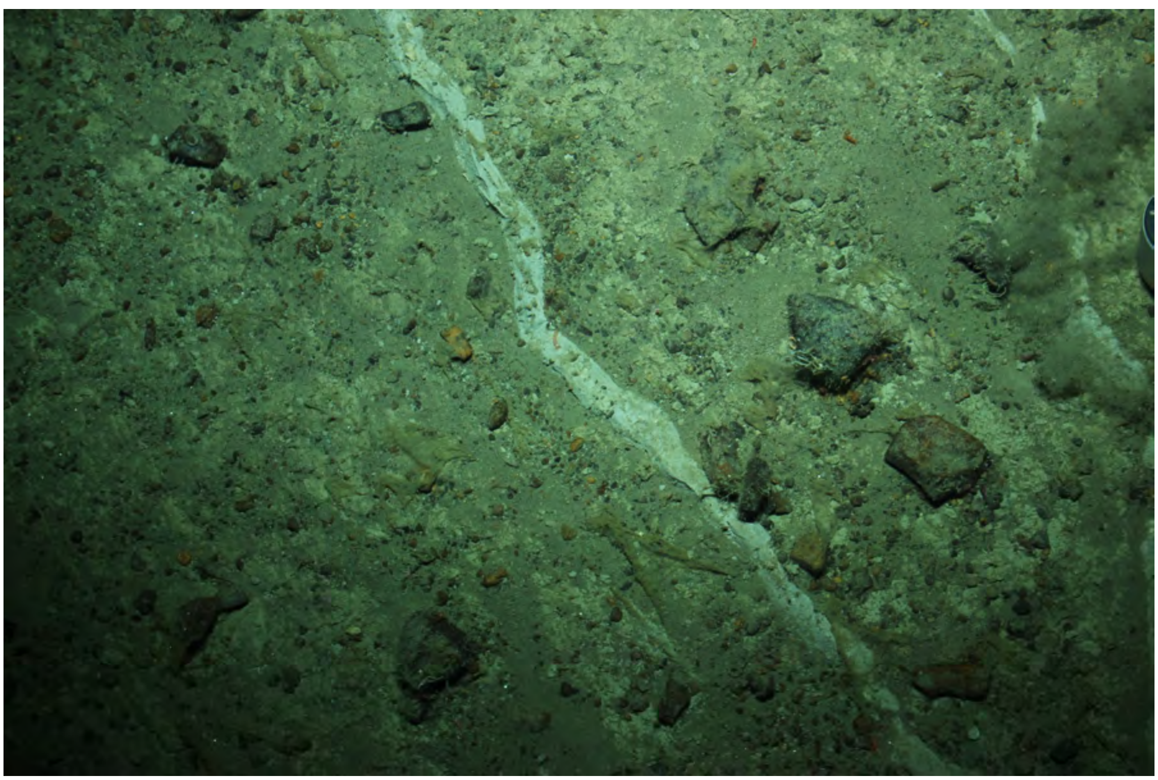

Photo 5. *Mud rivulet on flank of newly discovered mud volcano on the slope just west of Dixon Entrance showing angular fragments of dark-colored rock, mud, and gravel (Photo P51, Survey Area 3).*

A nighttime 3.5-kHz sub-bottom profiling survey was undertaken off western Dixon Entrance in the transboundary area of Survey Area 3, in an area sparsely covered by MBES bathymetric data (Fig. 7) with a return in the morning to the volcanic-like cone to collect IKU grab samples.

Grab 1 (Station 32). The first IKU grab sample of the day was at a site of photographed carbonate crusts, bacterial mat, and gravel as seen in photo P180. The grab was full of mud/clay, gravel, clams, mussels, and cemented mud and had a strong smell of H_2S; two short core sub-samples were taken in sediment of the grab to be used for future stratigraphic analyses.

Grab 2 (Station 33). The second IKU grab for the day was taken near what appeared to be a volcanic rock outcrop on photo P88. The grab was full and recovered small volcanic clasts (some angular), gravel and sand. A short core sub-sample was taken from grab for future stratigraphic analyses.

Grab 3 (Station 34). The third IKU grab sample of the day was taken in an area where phosphate coated rocks appeared to be exposed on the seafloor as observed in photo P309. The recovered grab was overflowing with mud, sparse gravel, pebbles and cobbles along with one angular concoidally-fractured basalt-like cobble. No core sub-samples taken.

Grab 4 (Station 35). The fourth IKU grab sample was collected in an area where gravel, pebbles, and cobbles appeared to be present as seen in photo P238. The grab was nearly empty with just a few (~12) clean pebbles and cobbles of apparent allochthonous plutonic clasts, carbonate tubes, phosphatically cemented angular sandstone, and one angular volcanic cobble.

Grab 5 (Station 36). The fifth and last IKU grab of the day was taken in an area that appeared in photo P90 to consist of volcanic rock outcrop or phosphatically coated carbonate slabs. A full grab sample was collected consisting of mud and small, rounded to sub-angular boulders, cobbles, and pebbles with some gravel. The lithology is mixed, but without lava or other in situ volcanic rock.

In the late afternoon of September 24th we shifted to a camera tow. A site approximately half way down the flank of the volcanic-like cone was selected to see if any lava or other volcanic rock was exposed that could be sampled. Description of result of the tow is given below:

Camera Tow 3 (Station 37). Photos taken during this short camera tow did not reveal lava or any other volcanic-like rock exposures. Photos primarily showed that the flank was covered with sandy gravel and rare boulders.

Transit from Survey Area 3 to Survey Area 4

A long easterly directed transit was made from the continental slope just west of Dixon Entrance to the Cape Felix, Alaska survey area. During this transect 3.5-kHz sub-bottom profiles were collected and showed that several faults, oriented primarily NW-SE and oblique to the trend of the main traces of the QC fault zone, are located on the continental shelf and exhibit seafloor expressions. Once in Survey Area 4 continued surveying until mid-day on September 25.

In Survey Area 4 large exposures of granite basement rock crop out on the seafloor and appear to have been differentially eroded along fractures and faults well exhibited in the MBES bathymetry (Fig. 9). A major structure consists of a well defined sharp linear fault depression filled with sediment along the eastern part of the image, whereas a more subtle, broader shear or fracture zone can be observed in the central part of the image, which is either covered with a thin layer of sediment or forms deeper sediment ponds. These faults may be associated with the QC-FW fault system and represent splays from the main fault traces located farther to the west and in the vicinity of Survey Area 3.

We selected five sites for coring based on the interpretations of the 3.5-kHz profiles and the MBES data (Fig. 9). A brief core description is provided below:

Core 30 (Station 38). The first core of the day was located in a fairly thick cover of sediment just east of the major NW-SE-trending fault observed in the MBES image. A nearly 4-m-long core of mud was recovered, which had a strong H_2S smell to it.

Core 31 (Station 39). The second core of the day was located in a thin sediment wedge that overlies a thick sediment pond at the northern end of the NW-SE trending shear zone. An ~3 m core of mud and sand was recovered with very hard (bedrock) fragments stuck in the core catcher.

Core 32 (Station 40). The third core of the day was located in a sediment field that thins and laps westward onto the NW-SE trending fault in the eastern part of the survey area. The core recovered approximately 5 m of mud.

Core 33 (Station 41). The fourth core of the day was located near a granite outcrop in a very subtle fault zone east of the shear zone, a very narrow target. The recovered core consisted of about 4 m of mud, with very stiff mud in the core catcher, and sand near the top of the core, and large foraminifera scattered throughout the surface sediments.

Core 34 (Station 42). The fifth core of the day, and last core of the cruise, was located south of the Cape Felix Survey Area 4, in a sediment pond that was observed in the 3.5-kHz profile to fill an apparent fault depression (see Fig. 9 for location). A nearly 5 m long core of mud with stiff clay in the core catcher was recovered.

Ended the cruise in the afternoon of September 25 and transited to Prince Rupert, B.C. to disembark scientific party.

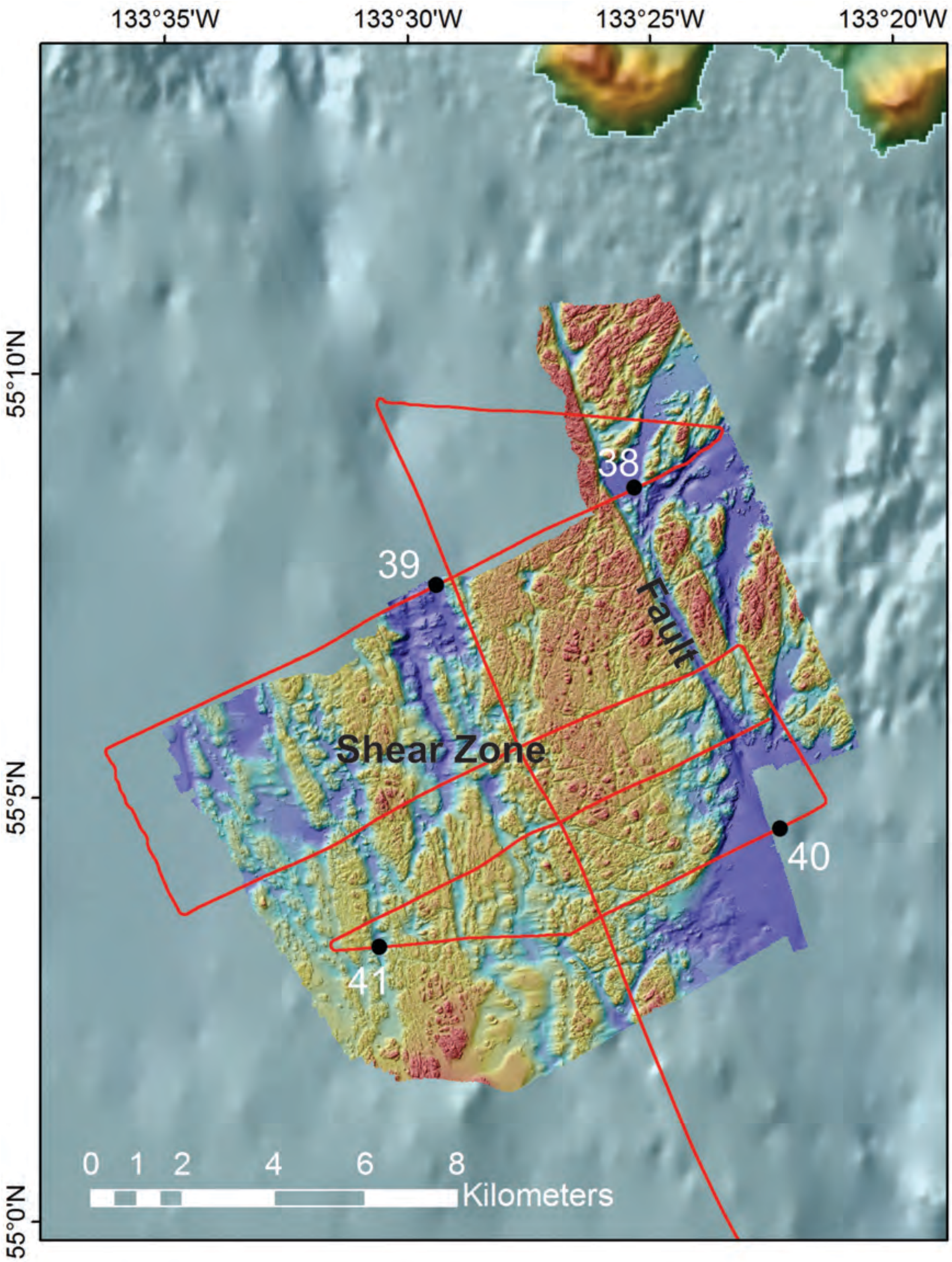

Figure 9. *MBES map of the Cape Felix area, Survey Area 4. Rough surfaced areas are granite while irregular and hummocky areas are mixed soft sediment-covered hard bedrock (granite) and blue represents deeper areas of soft unconsolidated sediment. The very linear and sharp NW-SE oriented depression on the eastern part of the image is a sediment filled fault while the sheared-looking area in the central part of the image is a*

fracture zone. Sediment areas within the fault and sheared zone were selected for coring to determine age. Red solid lines are 3.5-kHz profile tracklines, black dots represent core locations and white numbers refer to Station number. Source: Alaska Department of Fish and Game.

Discussion

The cruise was highly successful and we continuously collected data during the 10-day, 24 hour/day operation. During the past year, after the collection of the data, the cores have been split, described, and fully logged by Vaughn Barrie and Kim Conway of the Geological Survey of Canada and the seismic-reflection profiles loaded into Kingdom Suite and partially interpreted. The major objectives of the cruise were: 1) to collect data that could be used to estimate slip rates along the QC-FW transform fault system; 2) to validate the estimated 3-4 m of seabed movement associated with the 2012 M 7.7 Haida Gwaii earthquake, which is currently being assessed; 3) to survey an area off Dixon Entrance that may be prone to mass wasting; and 4) to investigate the possible partitioning of slip onto faults east of the main splay of the fault system. Although each of these objectives were addressed and data collected to help answer the questions, the most surprising part of the cruise was the evidence found for fluid flow along the fault system and the difficulty encountered in trying to collect long cores in the vicinity of the QC-FW fault zone offshore of Haida Gwaii.

Partitioning of Slip

The MBES image of the QC fault zone collected by the Canadian Hydrographic Service illustrate the linearity of the structure offshore of western Haida Gwaii (Fig. 10).
To determine slip rate along the fault zone four different piercing points consisting of Cartwright canyon, and three gullies that appear to have been offset by the fault zone were selected for measurements (Fig. 11). By matching the walls and thalwegs of the canyon and gullies a consistent 800 ±50 m of offset was restored with a high degree of confidence. To obtain the age of offsets an average date of 14.5 ka was used based on the time that the glaciers of Haida Gwaii retreated or melted. This date is based on the study of glacial retreat reported by Barrie and Conway (1999). It was reported from ^{14}C radiometric age dating that maximum glaciation took place approximately 16.0 to 15.0 yr. BP (Blaise et al., 1990) with deglaciation beginning around 15.0 yr. BP and marine ice-free areas occurring approximately 13.5 to 13.0 yr. BP (Barrie and Conway, 1999). During the Last Glacial Maximum (LGM) Haida Gwaii appears to have acted as an ice shadow preventing the glaciers from extending westward onto the narrow western shelf of the archipelago, thus starving the area of glacially derived sediment. However, during deglaciation a flood of sediment was introduced to the shelf and slope of western Haida Gwaii from small alpine glaciers, which acted as point sources for sediment being supplied to erode, and transported through, the canyons and gullies along the shelf and slope of the archipelago. Due to lack of significant sedimentation during the Holocene these erosional features were preserved as seafloor expressions and not buried, thus producing excellent features to use for piercing points. This abrupt cessation of sediment supply appears to have occurred sometime around 14.5 ka ±0.5 ka with little or no significant Holocene sediment being deposited afterwards. Thus, an offset of 800 ±50 m for the past 14.5 ka equates to a slip rate for the QC fault of approximately 55 mm/yr.

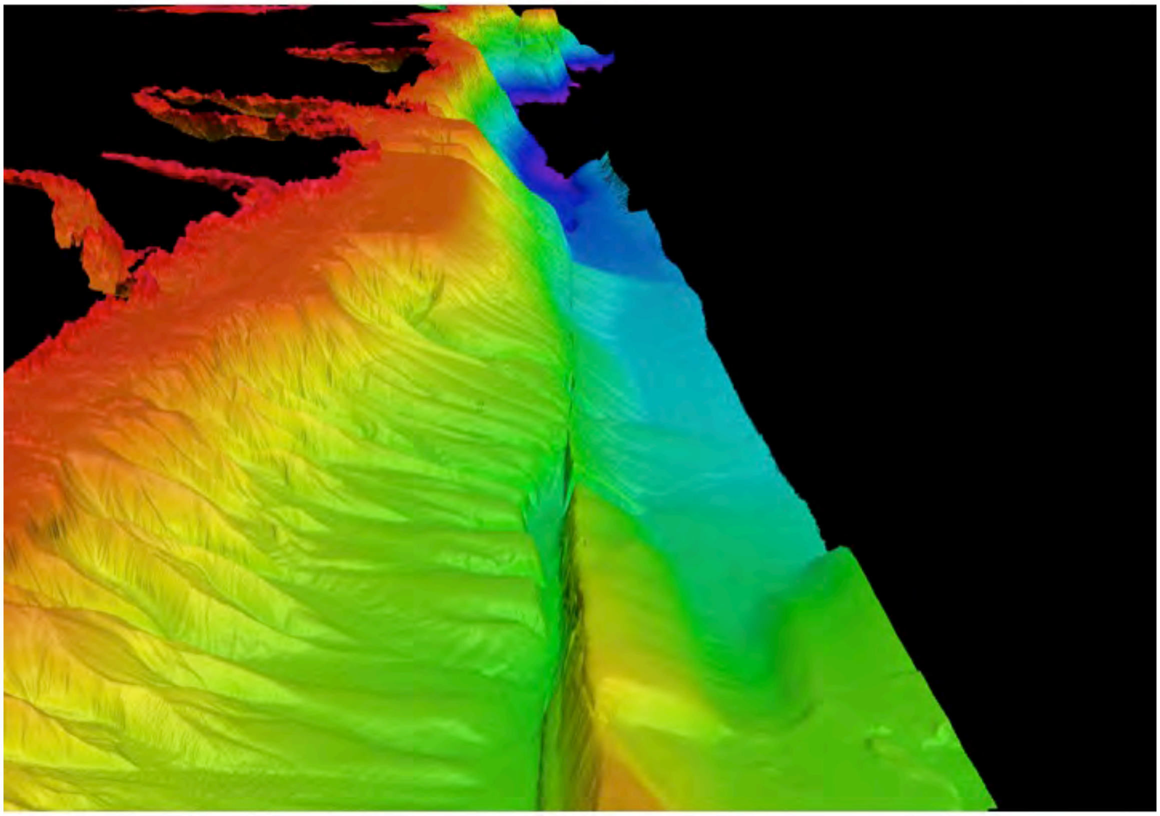

Figure 10. *A MBES image of the Queen Charlotte fault zone offshore and west of Haida Gwaii Island; looking south along the straight edge of the western side of the zone. Bathymetric data from the Canadian Hydrographic Service, image courtesy of Daniel Brothers, USGS. See Figure 5 for location.*

Selected core sub-samples sent in for ^{14}C radiometric dating show three major ages for the sediment cored along the western margin of Haida Gwaii, consisting of 17, 21, and 42 ^{14}C yr/BP (Fig. 12; Table 1). This suggests that little sediment younger than 17 ka exists in the areas cored because significant sedimentation shutdown after the retreat of the glaciers and this supports the dates obtained by Blaise et al. (1990) and Barrie and Conway (1999). These radiocarbon results justify the 14.5 ka date used in the slip rate estimate (Greene et al., 2016).

A slip rate calculated by Brothers et al. (2016) for the most northern segment of the QC fault zone just seaward of Cross Sound near where the fault zone extends offshore from the Fairweather Range, and where the most recent (16 September 2017) M 4.3 earthquake occurred, is nearly equivalent to what we calculate (55 mm/yr) for the central part of the fault zone off western Haida Gwaii. An offset of 925 m ÷25 m along the glacially carved southern wall of the Yakobi Sea Valley, considered to be about 17 ka indicates a slip rate of 54 ±2 mm/yr (Brothers et al., 2015). This indicates that the entire relative plate motion of approximately 50-60 mm/yr as calculated by Prims et al. (1997) and Rohr et al. (2000) between the Pacific and North American plate is accommodated

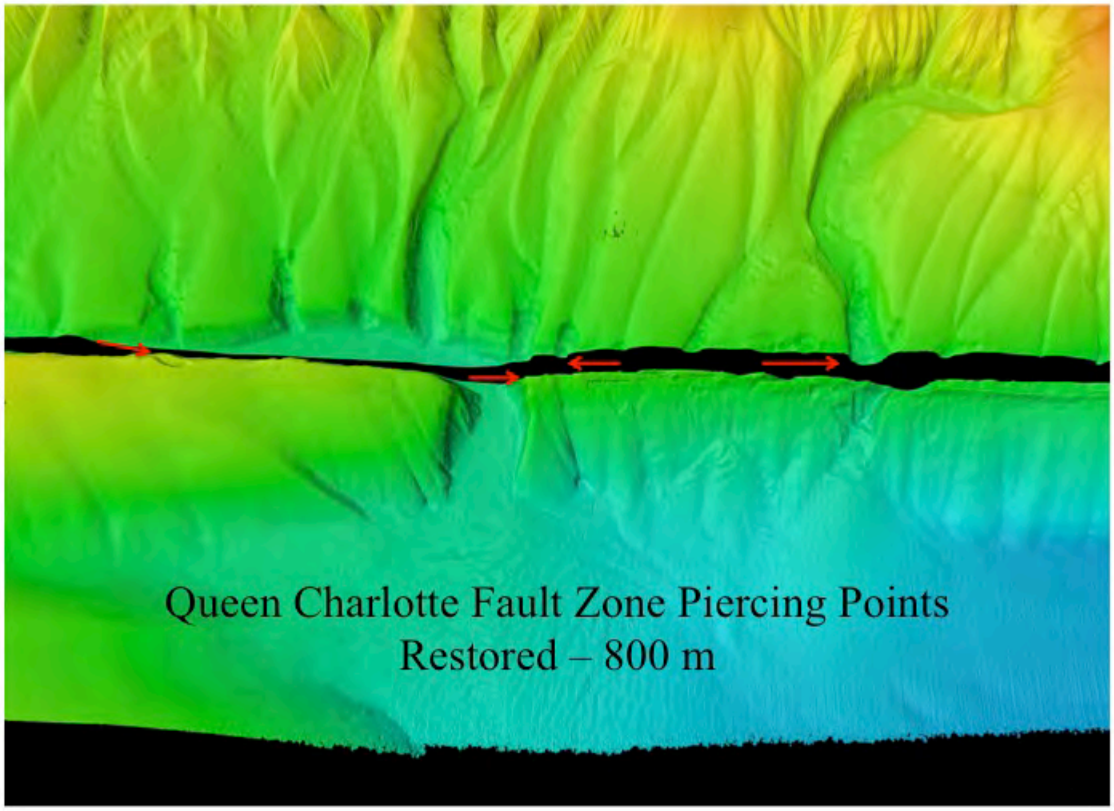

Figure 11. *MBES image of the Queen Charlotte fault zone showing the restored movement of 800 m based on offsets of canyon and gully walls and thalwegs as indicated by red arrows. Bathymetry collected by the Canadian Hydrographic Service; image courtesy of Daniel Brothers, USGS. See Figure 5 for location. See Figure 12 for unrestored image of this part of the QC fault zone.*

along the QC fault zone with no significant partitioning of motion being taken up on other faults. This lack of partitioning is further justified by the results of a study of the Chatham Strait fault zone by Conrad et al. (2016) that found no evidence for recent offsets along the faults of this zone.

Fluid Flow

A major surprise of the cruise was the discovery of an apparent mud volcano on the continental slope just west of Dixon Entrance (Survey Area 3, Fig. 7). Here a well-defined cone-like structure with a crest located at 1,000 m water depth was profusely venting gas 700 m into the water column from two different vents within a small crater at the crest, as shown in the 18-kHz sounder profile (Fig. 8). We did not sample the gas, but speculate that it contains methane as chemosynthetic (methanogenic) communities in the form of high concentrations of living *Calyptogena* clams (Photo 2) and mussels were observed in the bottom photos and sampled with the IKU grab. In addition, extensive areas of carbonate slabs and chimneys, *Biggiotoa* bacterial mats and a single

Vestimentiferin tubeworm was observed in the bottom photos (Photos 4 and 3) close to the vents, which also suggest the presence of methane.

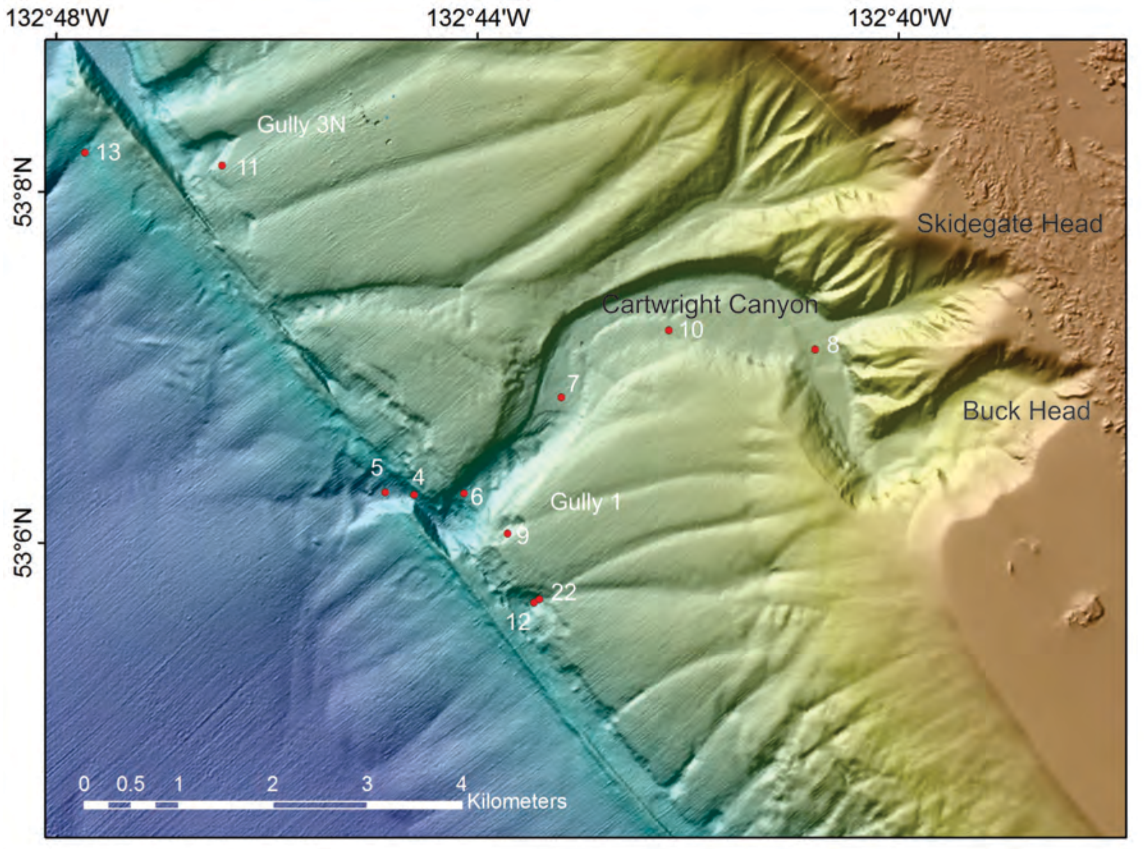

Figure 12. *Locations of piston cores (numbered red dots) taken in and around Cartwright canyon. Core descriptions, log and photos are posted in Appendix II. See Table 1 for coordinates and dating results of all cores collected including the ones shown in this figure.*

The 3.5-kHz sub-bottom profiles obtained during the geophysical investigation of Survey Area 3 show the existence of other cone-like features and a hummocky and deformed seafloor characteristic of landslides. Therefore, we infer that the upper continental slope west of Dixon Entrance is unstable and prone to mass wasting, probably the result of fluid flow and gas expulsion.

Elsewhere, within Survey Areas 1 and 2, evidence of fluid flow along the QC-FW fault system was observed. Two large volcanic-shield-like cones located near the southern terminus of the fault system just north of Cape St. James of Haida Gwaii (Survey Area 1) are venting gas (Fig. 4). We were able to cross the crest of one of these cones and recorded in the 18-kHz sounder data a plume rising above its crest; the crest of the other

Table 1:

Lab Number	Sample Number	Cruise Number	Station Number	Sample Interval	Material	^{14}C age BP	±
UCIAMS							
167530	201504-02232	2015004PGC	2	232	Shell	14095	35
167531	201504-0371	2015004PGC	3	70-72	Shell	12005	30
167532	201504-0539	2015004PGC	5	38-40	Shell	39080	690
167533	201504-09129	2015004PGC	9	129	Shell	42870	1100
167534	201504-1528	2015004PGC	15	27-29	Shell	21320	80
167535	201504-1631	2015004PGC	16	31	Shell	13450	35
167536	201504-1648	2015004PGC	16	48	Shell	49390	2500
167537	201504-16165	2015004PGC	16	165	Shell	16190	45
167538	201504-1928	2015004PGC	19	27-28	Shell	14110	40
167539	201504-1940	2015004PGC	19	39-41	Shell	13620	35
167540	201504-20109	2015004PGC	20	109	Shell	20980	80
167541	201504-2315	2015004PGC	23	14-16	Shell	13460	35
167544	201504-38340	2015004PGC	38	339-341	Shell	3580	20
167545	201504-39276	2015004PGC	39	275-277	Shell	6500	20
167546	201504-39386	2015004PGC	39	385-387	Shell	10955	25
167547	201504-39412	2015004PGC	39	411-413	Shell	10710	25
167548	201504-4133	2015004PGC	41	33-34	Shell	3825	20
167549	201504-41129	2015004PGC	41	128-130	Shell	7680	20
167550	201504-41146	2015004PGC	41	146	Shell	10690	25
167551	201504-42150	2015004PGC	42	148-151	Shell	10730	25
167552	201504-42171	2015004PGC	42	170-172	Shell	11015	25
167553	201504-42225	2015004PGC	42	224-226	Shell	11505	30
167554	201504-42286	2015004PGC	42	285-288	Shell	11975	30
167555	201504-42361	2015004PGC	42	360-362	Shell	12560	30

Table 1. *Radiometric age dates obtained from core samples. See core log (Appendix II) for core descriptions and see Figures 4,5,6, 7, 9, and 12 for locations.*

cone was missed in the crossing and thus a plume was not observed. Although these volcanic-like edifices appear associated with a magmatic source, we speculate that they could also be mud volcanoes similar to, but larger than what we found in Survey Area 3.

In Survey Area 2, offshore of west-central Haida Gwaii, two additional gas plumes were imaged in the 18-kHz dataset. One was emanating from the mouth of a gully truncated by the QC fault zone just south of Cartwright canyon and north of a heavily gullied slope that appears to represent fluid induced gulling. The other was emanating from the base of a landslide glide block at the distal edge of the large landslide located east of the fault zone and north of the rift valley opening (Fig. 4).

It appears that gas expulsion and fluid flow is prominent along most of the QC fault zone from Cape St. James to Dixon Entrance. We consider this southern segment of the fault zone to be very leaky along most of its length, as in each of our survey areas we found gas plumes that originate close or within the fault zone and speculate that the faults are acting as conduits for the venting of the gases and fluids. The origin of the gas can be from multiple sources such as from the compaction and degradation of organic-rich sediment as well as from continuously forming hydrocarbon resources (Tinivella and Giustiniani, 2013), and dissolution of clathrates or frozen gas hydrate systems (Dimitrov, 2000; Depreiter et al., 2005; Sauter, et al., 2006; Tinivella and Giustiniani, 2013). Heat at depth, such as from a magmatic source also has the potential of producing mud volcanoes (Tinivella and Giustiniani, 2013) especially along convergent margins.

Densification of Sediment

Our inability to obtain long piston cores within the survey areas of the QC fault zone because of the high density and well-packed sediments was surprising. We speculate that the reason for this densification is associated with one of two causes, or perhaps both. First, during the LGM Haida Gwaii Islands acted as an ice shield along the continental shelf of B.C. preventing the glaciers and glacial-fed sediment from reaching the distal edge of the shelf and upper slope. This created a sediment starved area west of Haida Gwaii, which may prove out that the sediment recovered in our cores are quite old, late Pleistocene in age. Second, the fairly high recurrence level of medium to large magnitude earthquakes along the QC fault zone may have increased the density of the sediment through shaking and packing. The combination of both a sediment-starved slope and densification could result in a more stable slope that is difficult to penetrate using gravity or piston corers.

In contrast, but also surprising to us, is that our longest cores of the investigation were obtained on the shelf in relatively shallow waters offshore of Cape Felix, Alaska (Survey Area 4). These cores were collected from sediment ponds associated with a well-defined linear fault and a fracture zone within differentially eroded granite rock exposures (Fig. 9). A probable explanation for recovering such long cores is that the shelf here is not starved of sediment and that unconsolidated Holocene, sediment trapped in the fault depressions is protected from sorting and winnowing by bottom currents. In addition, a lack of moderate to large magnitude earthquakes since deposition of the sediments did not have the effect of densification of sediment as appears to have occurred along the QC fault zone.

Conclusions

This investigation was highly successful in the amount and type of data collected. Weather was excellent throughout the cruise and no major equipment failures occurred. The only problem encountered was the loss of the power supply for the MSCL, which resulted in the inability of having the core logger automatically run the cores through the sensors. Nevertheless, all but one sensor, the velocity sensor, was utilized by hand pushing the cores through the system and all cores were fully logged at the shore lab in Sidney. Both the ships officers and crew and Geological Survey of Canada technicians worked hard to assure that good quality data were acquired and properly recorded.

Over 900 km of 3.5-kHz sub-bottom seismic-reflection, 18-kHz and 12-kHz echosounder water column acoustic profile data were obtained during the cruise (see Appendix I for data logs and water column images; acoustic profiles can be provided upon request and copies exist at the USGS in Santa Cruz). Forty-two cores (see Appendix II for core descriptions, photos, and logs), grab samples, and camera transects (see Appendix III for complete set of photos and positions; to be transmitted separately but on file at the USGS in Santa Cruz) were made with the collection of 30 cores at 34 core stations (4 no recovery and 2 little recovery, an ~89% recovery rate). Five IKU grab stations and three camera tow stations were also made with all grabs being full to overflowing with sediment and excellent photos obtained by the towed drop camera.

We identified four canyon and gullies piercing points that we are confident represents offset along the QC fault zone in the past 14.5 ka. The ^{14}C dates (see Table 1 and Appendix II) obtained from the cores in and around Cartwright canyon suggest that certainly by 17 ka sediment supply and significant erosion of the canyons and gullies along the western margin of Haida Gwaii began to shut down. This suggests that by 14.5 ka little or no erosion was occurring along the downslope area along western Haida Gwaii.

Five gas plumes were identified and appear to be associated with mud volcanoes, landslides and gullies within or in the vicinity of the QC fault zone (see Appendices I and III). Four of the five plumes were newly discovered with one, located at the crest of a shield-like volcanic cone offshore of Cape St. James, Haida Gwaii (Survey Area 1), having been described before. Extensive chemosynthetic communities were found to be associated with the newly discovered mud volcano west of Dixon Entrance (Survey Area 3). In addition to these communities, large areas of carbonate cementation and bacterial mats were found. This suggests the presence of methane. Non-living *Calyptogena*-like clams were observed in the photos taken during Camera Tow 1 along the recent fault rupture scarp offshore of central Haida Gwaii (Survey Area 2), also suggesting the presence of methane.

A major question arising from the discovery of what appears to be ubiquitous gas and fluid seeps along the QC-FW fault system is: "How do such fluids effect fault movement?" We conclude that faults of the system are acting as conduits for the fluids, but wonder how friction along the fault planes are being reduced, if at all, by the presence of the gases? Further work in this field is certainly needed.

In addition, it has been reported (Bonini, 2012) that trends of mud volcanoes can be used as indicators of stress orientations and tectonic controls. Our surveys suggest, especially in Survey Area 3 west of Dixon Entrance, that there are more mud volcanoes along the slope within the QC fault system that may display a consistent orientation that could be used to evaluate tectonic stress in this region. This type of evaluation would supplement our present approach in evaluating piercing points along the fault zone for the purpose of assessing slip rates. We, therefore, conclude that a detailed, comprehensive MBES survey should be undertaken in Survey Area 3 to provide critically needed data for use in the evaluation of the tectonic controls on fault motion in that region.

Coordination

Throughout the past year and after the completion of the *Tully* cruise scientific coordination between the NEHRP participants and the USGS team involved in the investigation of the QC-FW transform fault system has taken place. Multiple trips were made by the PIs between Orcas Island and the Pacific Science Center in Sidney, B.C., and Santa Cruz, California, which cumulated in an end-of-the-year review on Orcas Island, October 2016 (see section on "Future – Recommendations" below). On 14 January 2016 PI Greene met with USGS team in Santa Cruz to discuss results of the *Tully* cruise. PIs Greene and Barrie met with USGS team in Santa Cruz 15-18 March 2016 to review results of core processing and age dating. PI Greene visited the GSC in Sidney B.C. 13-15 September 2016 to initiate report writing and preparation of data for publication with PI Barrie.

Reporting of Results, Publicity & Outreach

Four formal presentations (two domestic, two international) on the results of this USGS NEHRP funded study were presented at scientific meetings, a press release was issued through SSSC, and an article written by Rachel Berkowitz was published in AGU EOS (see Appendix IV for abstracts and Press Release). The first formal talk was given at the Seismologial Society of America's (SSA) Annual Meeting in Reno, Nevada April 20-22, 2016 and presented by Dr. Stuart Nishenko, with the second, third, and fourth presented by Dr. H. Gary Greene at the Annual GeoHab meeting in Winchester, England 2-5 May, 2016, at the Pacific Communities' Science, Technology, and Resources (STAR) meeting in Nadi, Fiji 6-8 June, 2016, and in San Francisco at the AGU Annual Meeting December 12-16, 2016 in a Special Session on Marine Geohazards chaired by Daniel Brothers, Janet Watt, and Katherine Maier of the USGS. Several newspapers in Alaska reported upon the information provided in the Press Release issued by SSSC and the radio station in Sitka commented on air about the results of the research. The EOS article can be found at the following URL: https://eos.org/articles/active-mud-volcano-field-discovered-off-southeast-alaska https://eos.org

In addition, the PowerPoint presentation for the AGU meeting in San Francisco has been shared with Bohyun Bahng of NOAA Federal (bo.bahng@noaa.gov). The PowerPoint slides were provided upon request after the presentation in San Francisco based on the interest of Bohyun Bahng who said they would be of great help to him in the consideration of potential marine geohazards of SE Alaska.

Future – Recommendations

Based on questions arising from the results of the USGS NEHRP-GSC funded *CCGS Tully* cruise and the discovery of a new mud volcano and several gas seeps along the QC fault zone, we investigated funding opportunities that would assist in continuing the studies of the fault zone and help answer questions we have about the seafloor conditions and potential geohazards. Pre-proposals were submitted and NOAA-OAR-OER-2017-2004629 for ship time in 2017 and to the Schmidt Oceanographic Institute (SOI) for *RV Falkor* time in 2018 to collect MBES data, investigate gas and fluid seeps and map potential unstable tsunamigenic slopes off Dixon Entrance in a poorly surveyed part of the Alaskan continental margin. We were invited to submit a full proposal to SOI but we were discouraged from submitting a full proposal to NOAA-OAR-OFR. However, after we organized a major international team of scientist interested in investigating the fluids along the QC-FW fault system and willing to donate time and effort for the study SOI opted not to fund our work for 2018. In addition, we sought support from NOAA's Hydrographic Office to obtain some MBES data in the Dixon Entrance area during the transit of the *Rainier* to and from its field survey areas in Alaska in 2016, but due to needed ship repairs this request was unfortunately not undertaken. We also investigated the possibility of using the University of Alaska's UNOLS *RV Sikuliaq* for the collection of MBES data during its transit from Alaska to San Diego, but the cost was prohibitive and our survey area was far off the transit route (see Appendix V for pre- and full proposals, justifications, and funding organizations' responses).

We convened a post-cruise meeting on Orcas Island to re-cap the *Tully* cruise results, to review USGS NEHRP, GSC, and USGS investigations of the QC-FW transform margin, and to plan future work (Fig. 13). This four-day workshop (October 25-28, 2016) was very successful and plans were made for USGS-GSC supported *Tully* cruise to take place in September 2017. Below is the list of participants to the meeting:

Dr. Vaughn Barrie	Marine Geologist	Geological Survey of Canada, Pacific
Dr. Danny Brothers	Marine Geologist	U.S. Geological Survey, Pacific, Santa Cruz
Mr. Jamie Conrad	Marine Geologist	U.S. Geological Survey, Pacific, Santa Cruz
Mr. Kim Conway	Marine Geologist	Geological Survey of Canada, PacificDr.
Dr. Amy East	Geologist	U.S. Geological Survey, Woods Hole
Dr. H. Gary Greene	Marine Geologist	MLML/Tombolo Mapping Lab
Dr. Katie Maier	Marine Geologist	U.S. Geological Survey, Pacific, Santa Cruz
Dr. Nathan Miller	Marine Geologist	U.S. Geological Survey
Dr. Stuart Nishenko	Seismologist	Pacific Gas & Electric Co., San Francisco
Ms. Tory O'Connell	Biologists	Sitka Sound Science Center, Sitka
Dr. Uri ten Brink	Marine Geologist	U.S. Geological Survey, Woods Hole

Other Attendees:

Mr. John Aschoff (Observer) – GIS Specialist, Friday Harbor
Dr. Rachel Berkowitz (Observer) – Journalist (Science, Nature, EOS)

Figure 13. *The post-cruise workshop on Orcas Island, WA showing intense discussion of results of the* Tully *cruise and the USGS mapping efforts.*

A major conclusion of the meeting was that it appears from both the estimated slip rates obtained by the USGS team at the northern end of the Queen Charlotte fault zone and by the USGS NEHRP supported team at the central part of the fault zone that the majority, if not all, of the relative plate motion between the Pacific and North American plates is being accommodated along the single major linear fault imaged in MBES data. The participants recommended that the portion of the fault zone not yet imaged by MBES be done so as soon as possible. Two major efforts were initiated to seek support to collect MBES data: 1) to seek support from NOAA NOS to be pursued by Daniel Brothers of the USGS and to seek support from the Canadian Hydrographic Service to be pursued by Vaughn Barrie of the GSC. A follow-up to these recommendations resulted in a conference call meeting with NOAA orchestrated by Daniel Brothers where the possibility of NOAA support was discussed and an agreement made between the GSC and the Canadian Hydrographic Service through Vaughn Barrie to image an area near Dixon Entrance that is in need of MBES coverage using the *CCGS Vector* (see Fig. 14).

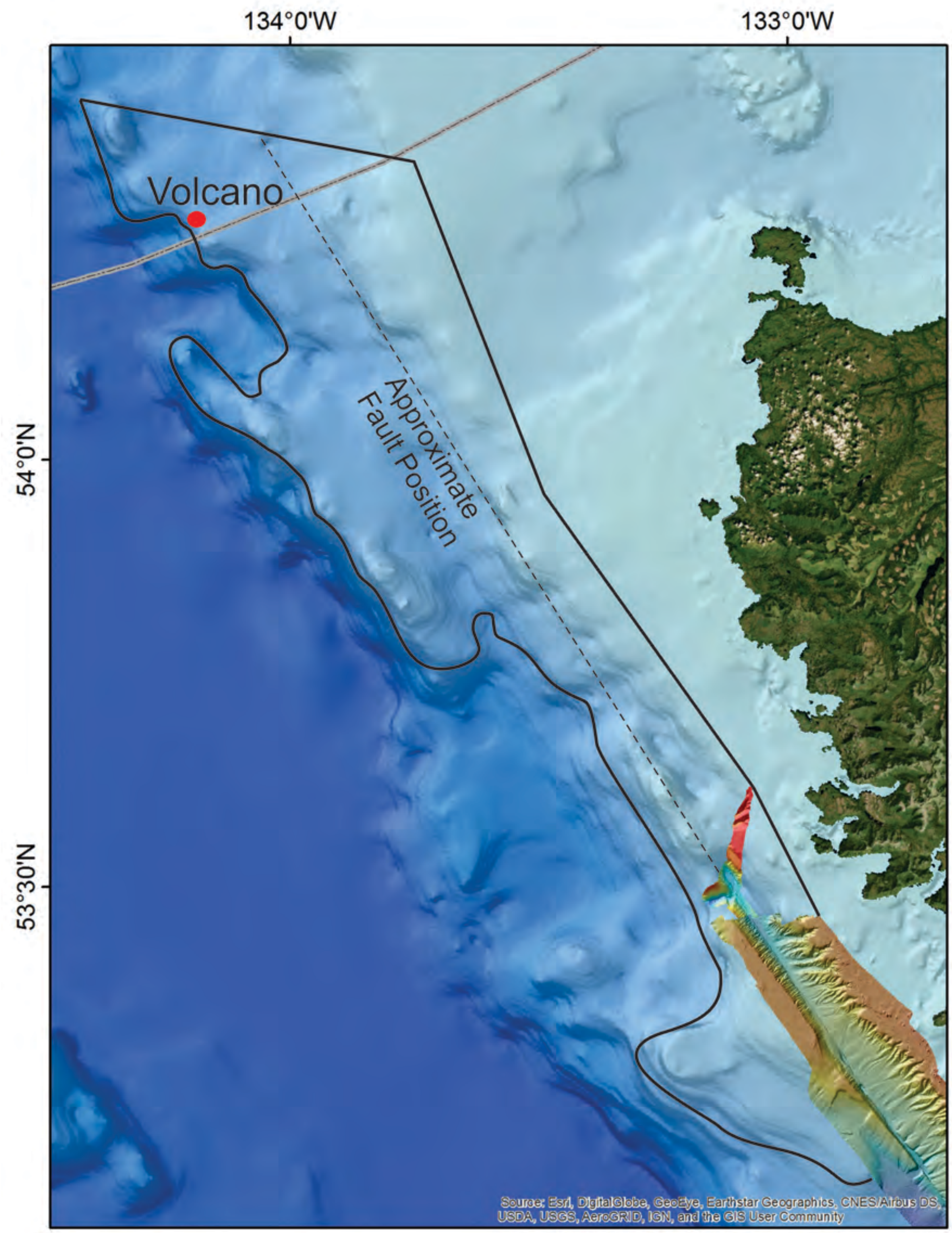

Figure 14. *Area proposed to be surveyed by the Canadian Hydrographic Service in 2017 using the CCGS Vector*.

The participants also recommended that additional piercing points be identified, additional cores be collected to validate the slip rates obtained from the last two years of study, and that marine benthic habitats be characterized and studied in relation to the tectonic processes occurring along the QC-FW fault system. This work is scheduled to take place on the upcoming *Tully* cruise in September 2016, a cooperative venture between the SSSC, GSC and USGS. A summary of the meeting is presently being written by Daniel Brothers.

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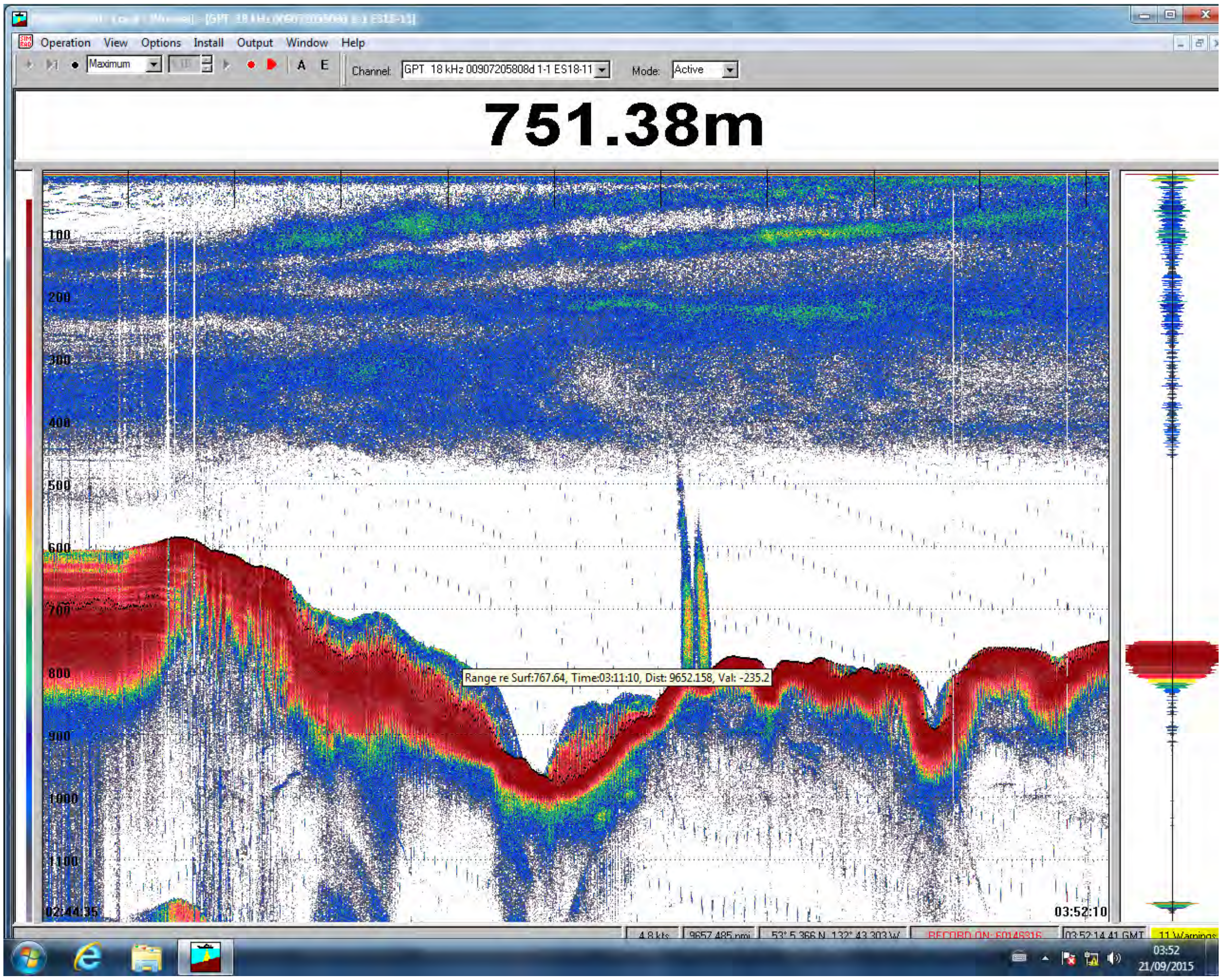
APPENDIX I

Acoustic Data Logs and Seep Images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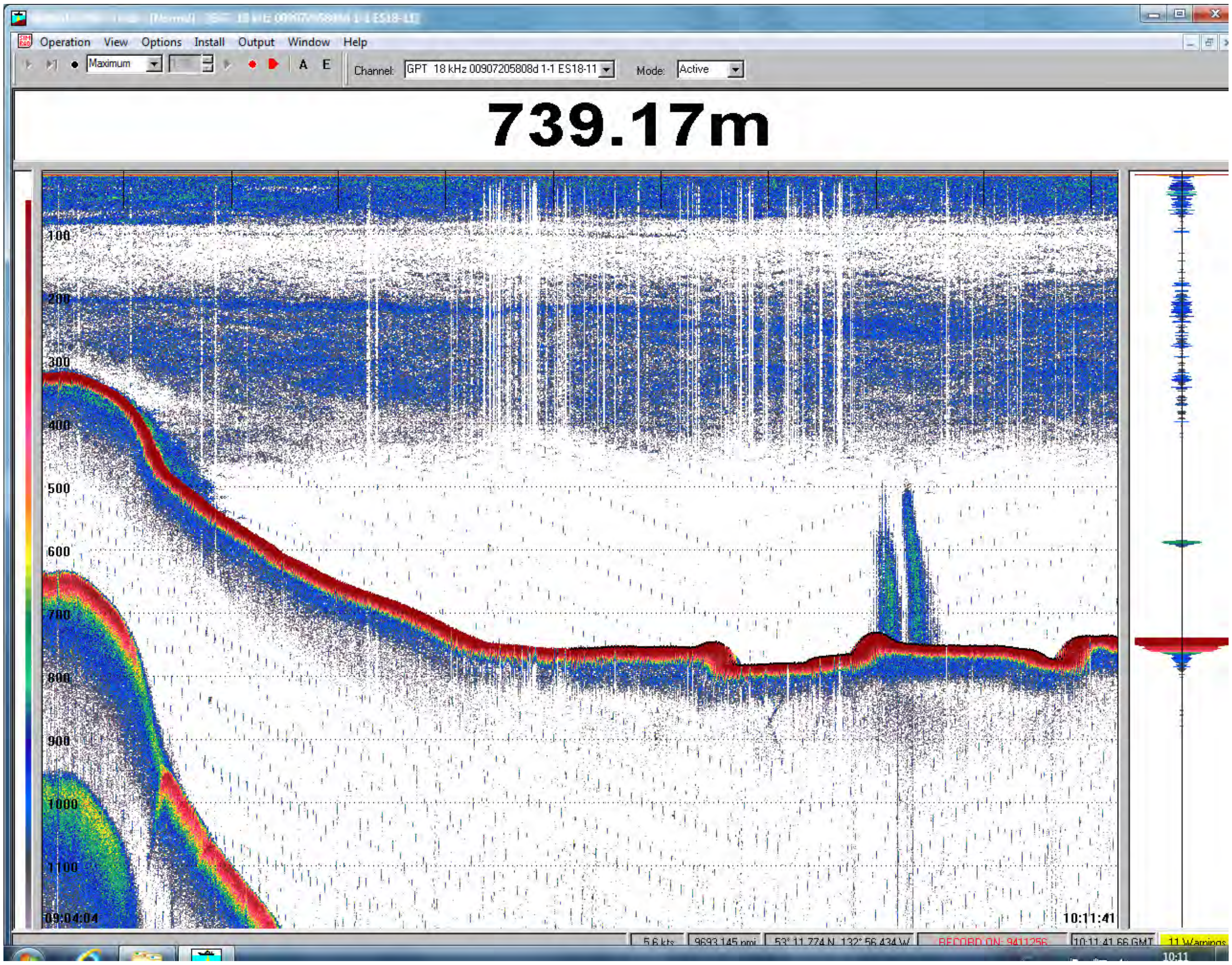
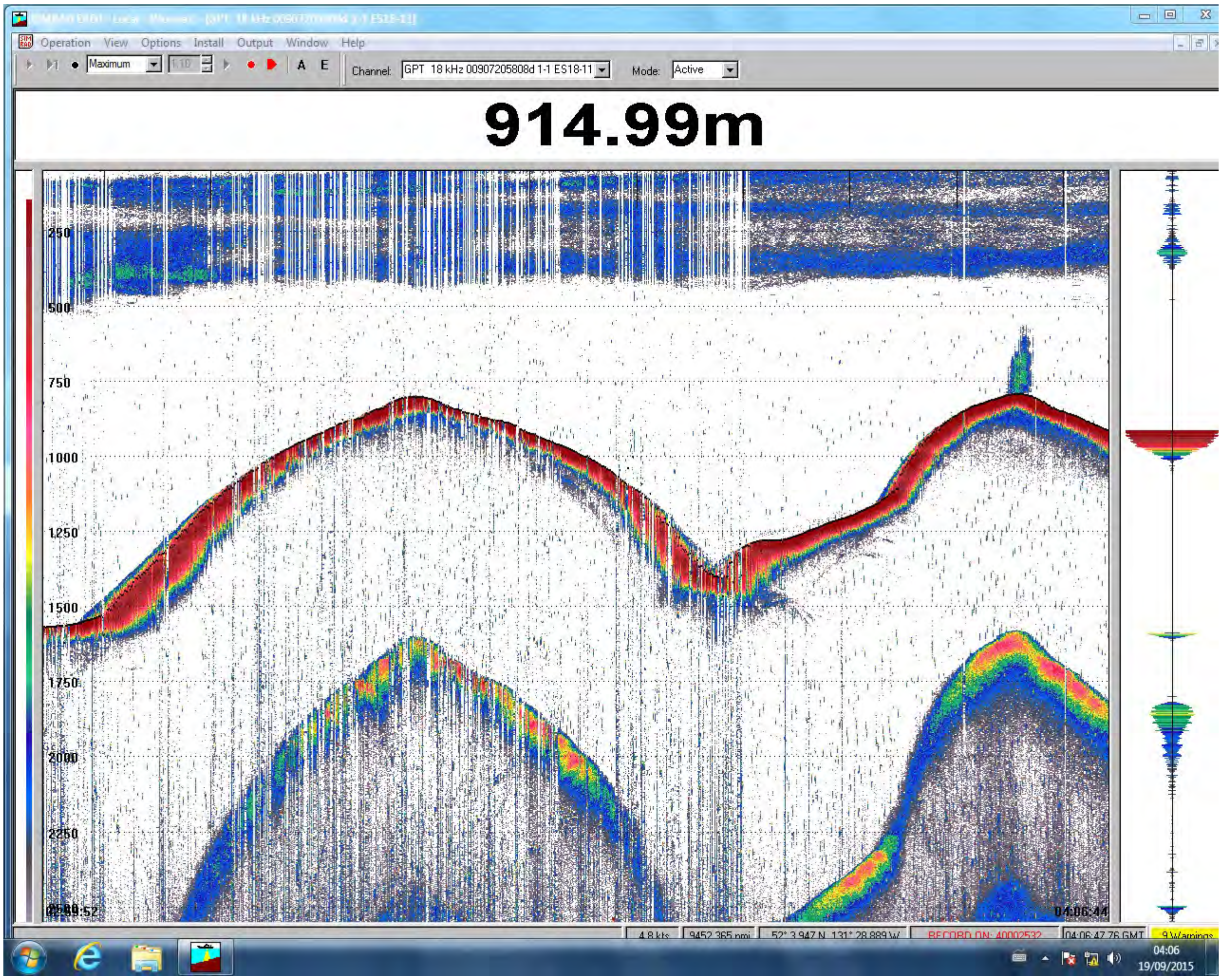
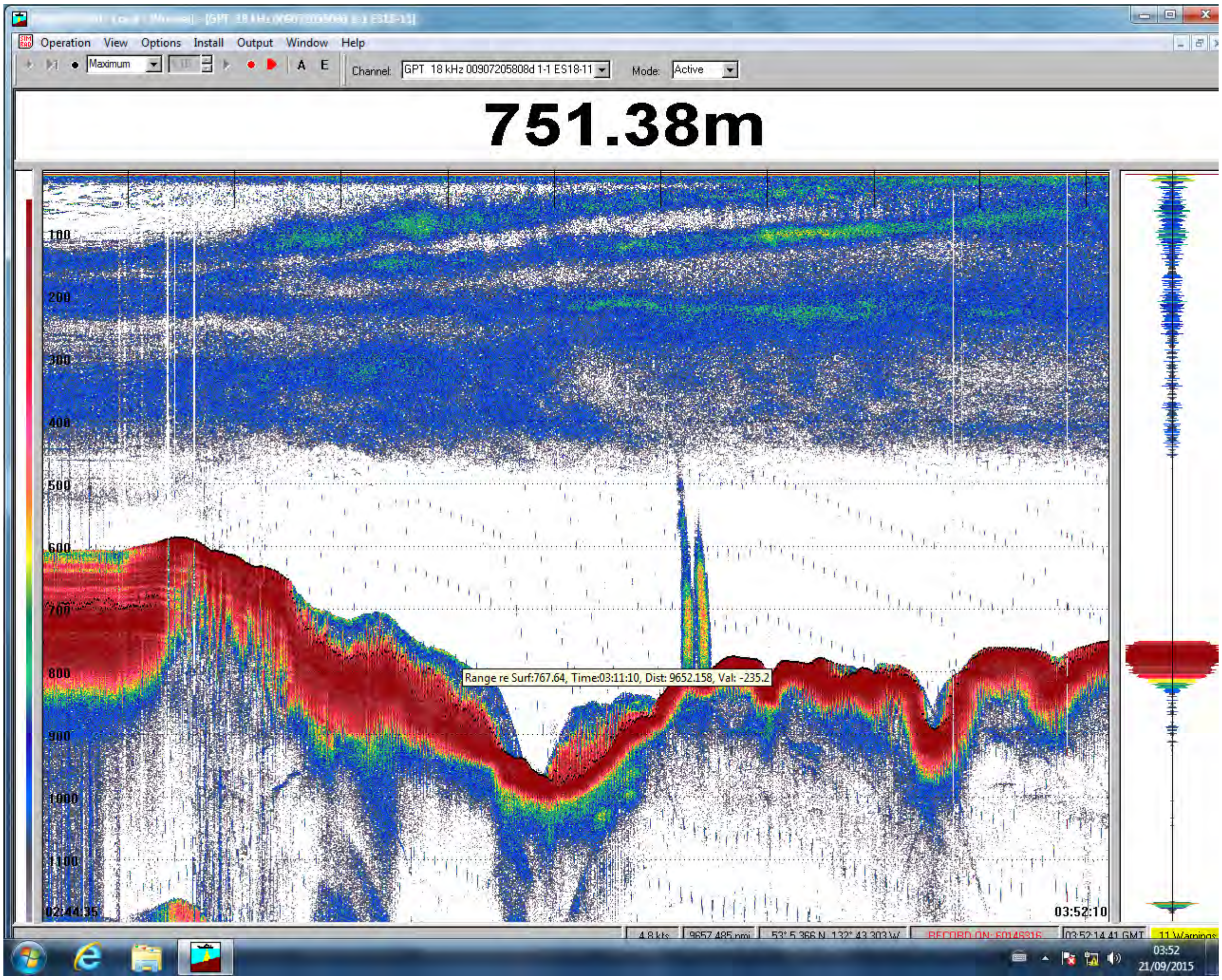
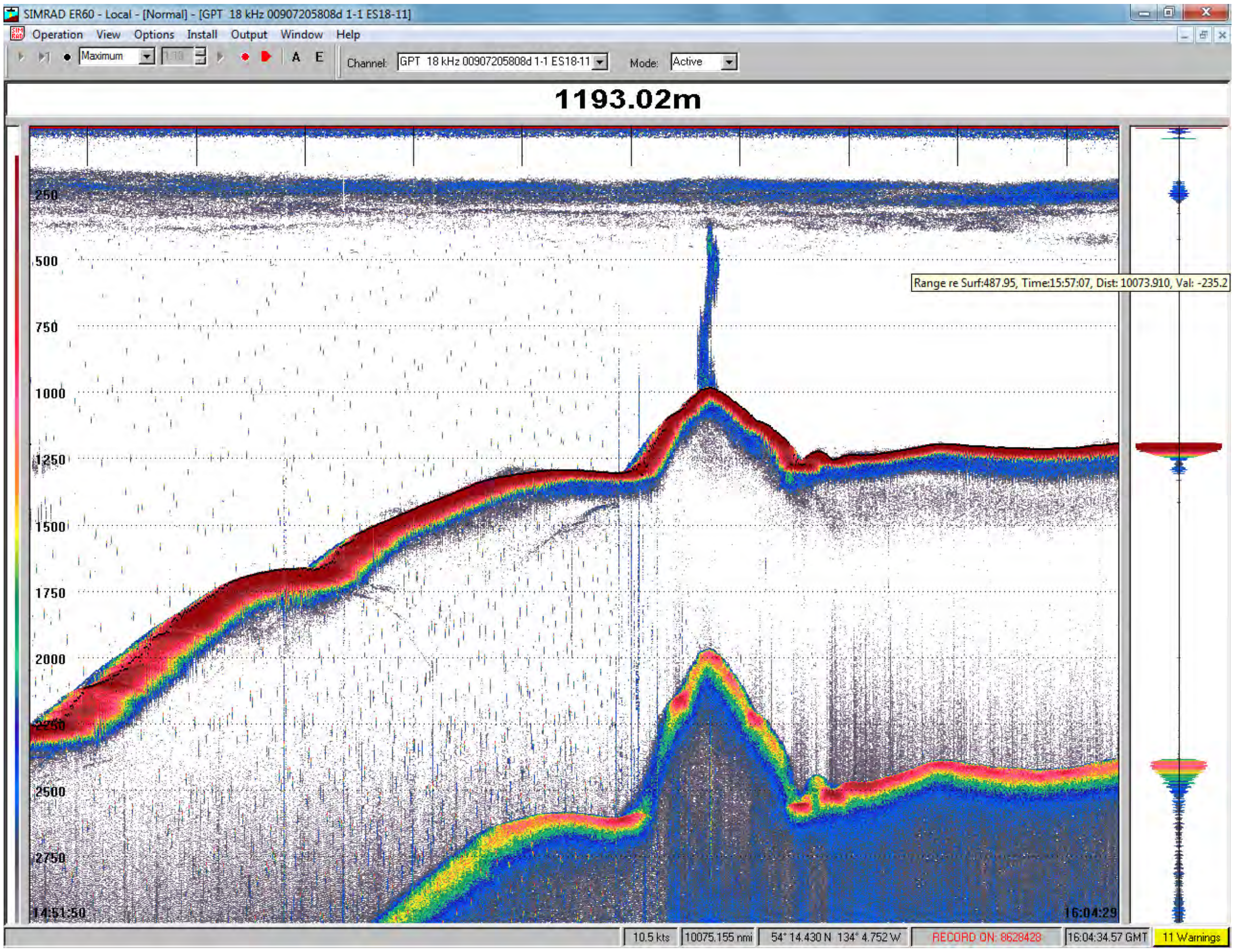
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
751.38m
Range re Surf:767.64, Time:03:11:10, Dist: 9652.158, Val: -235.2
02:44:35
03:52:10
4.8 kts
9657.485 nmi
03:52
21/09/2015



Operation View Options Install Output Window Help
Maximum
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
739.17m
100
200
300
400
500
600
700
800
900
1000
1100
09:04:04
10:11:41


Operation View Options Install Output Window Help
Maximum
A E
Channel:
GPT 18 kHz 00907205808d 1-1 ES18-11
Mode:
Active
914.99m
250
500
750
1000
1250
1500
1750
2000
2250
04:06:44
4.8 kts
9452.365 nmi
52° 3.947 N 131° 28.889 W
RECORD ON: 40002532
04:06:47.76 GMT
9 Warnings
04:06
19/09/2015


Operation View Options Install Output Window Help
Maximum
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
751.38m
100
200
300
400
500
600
700
800
900
1000
1100
02:44:35
03:52:10
Range re Surf:767.64, Time:03:11:10, Dist: 9652.158, Val: -235.2
4.8 kts
9657.485 nmi
53° 5.366 N 132° 43.303 W
03:52:14.41 GMT
11 Warnings
03:52
21/09/2015



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Operation View Options Install Output Window Help
Maximum
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
1193.02m
250
500
750
1000
1250
1500
1750
2000
2250
2500
2750
Range re Surf:487.95, Time:15:57:07, Dist: 10073.910, Val: -235.2
14:51:50
16:04:29
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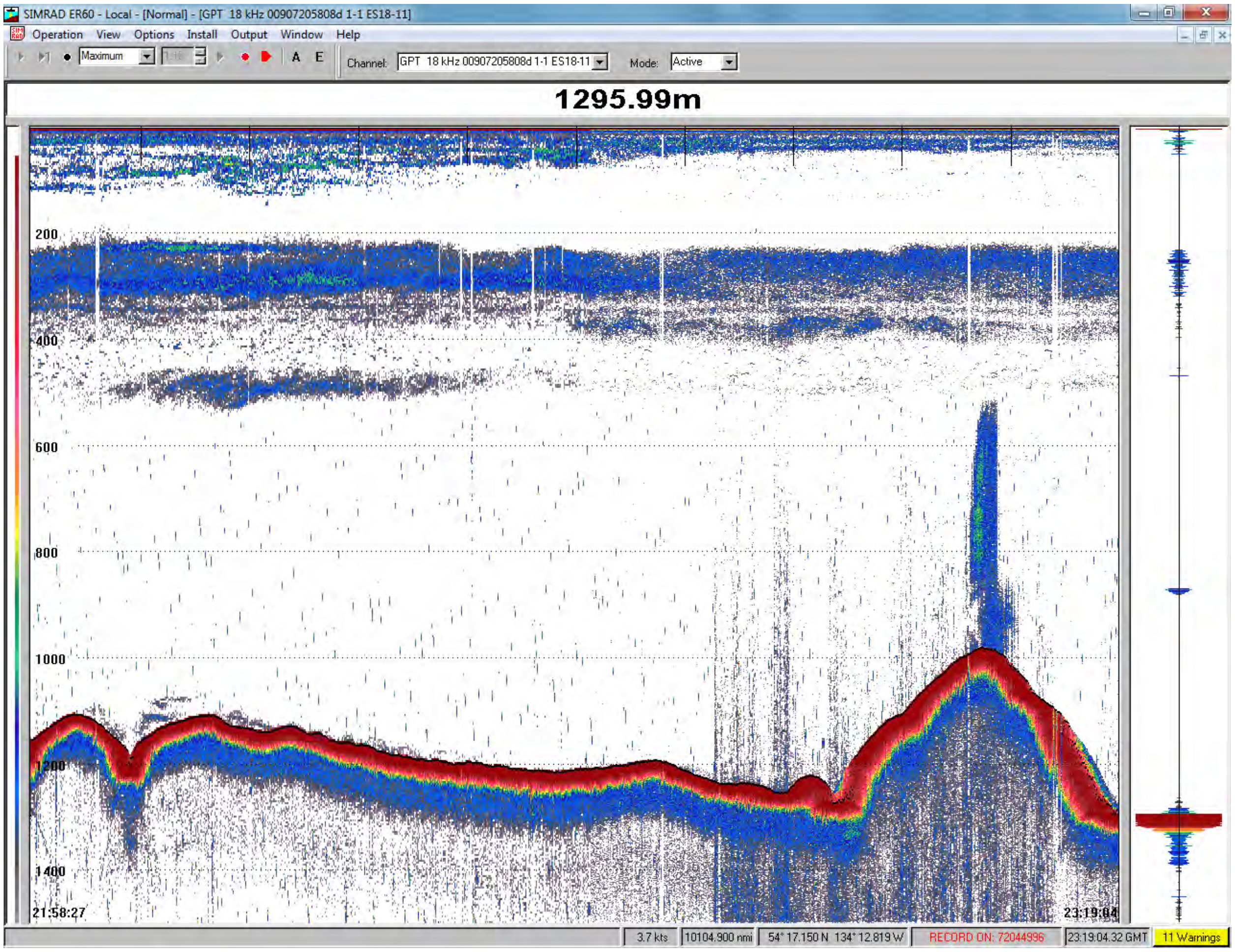
10075.155 nmi
54° 14.430 N 134° 4.752 W
RECORD ON: 8628428
16:04:34.57 GMT
11 Warnings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Operation View Options Install Output Window Help
Maximum
A E
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
1295.99m
200
400
600
800
1000
1200
1400
21:58:27
23:19:04
3.7 kts
10104.900 nmi
54° 17.150 N 134° 12.819 W
RECORD ON: 72044996
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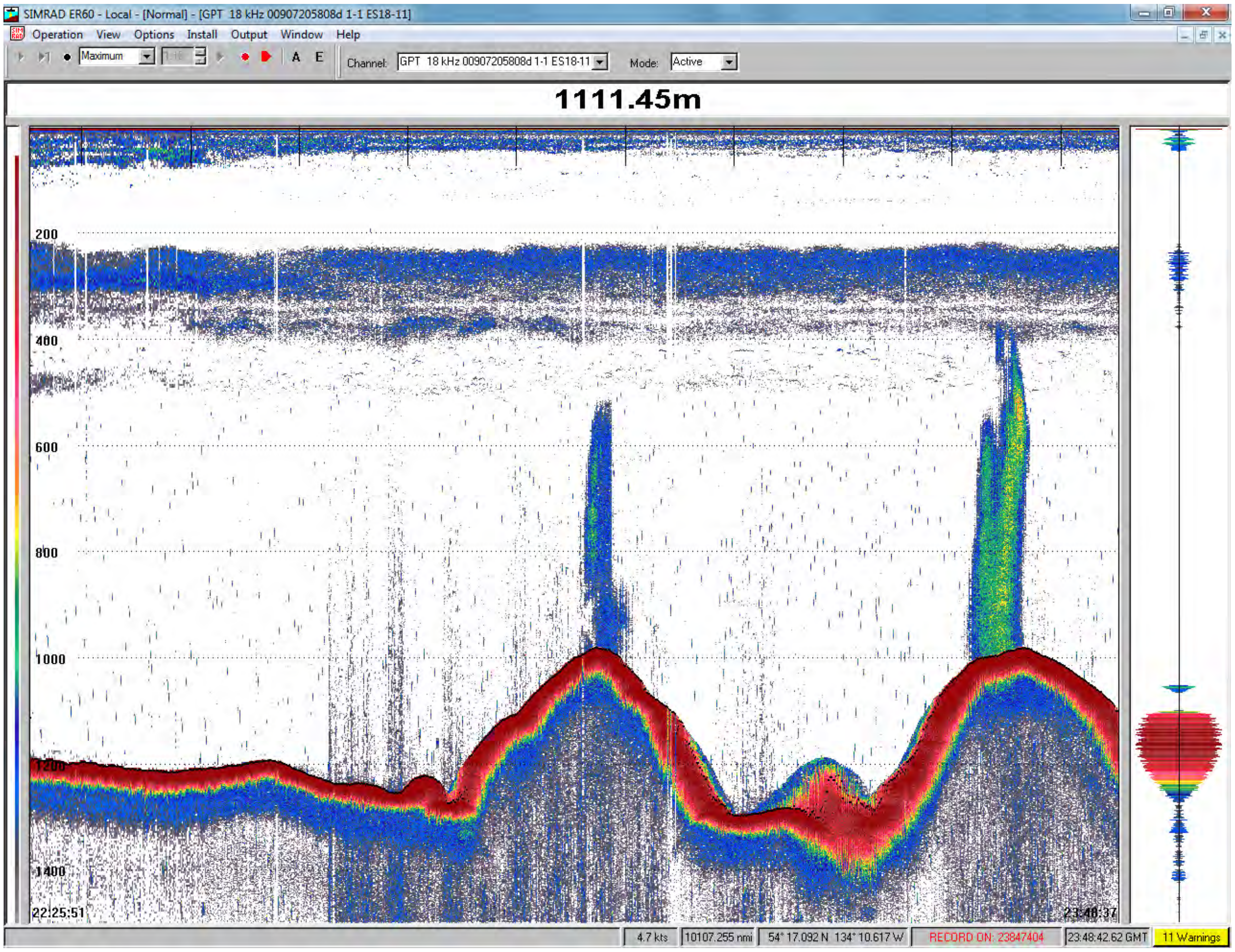
11 Warnings



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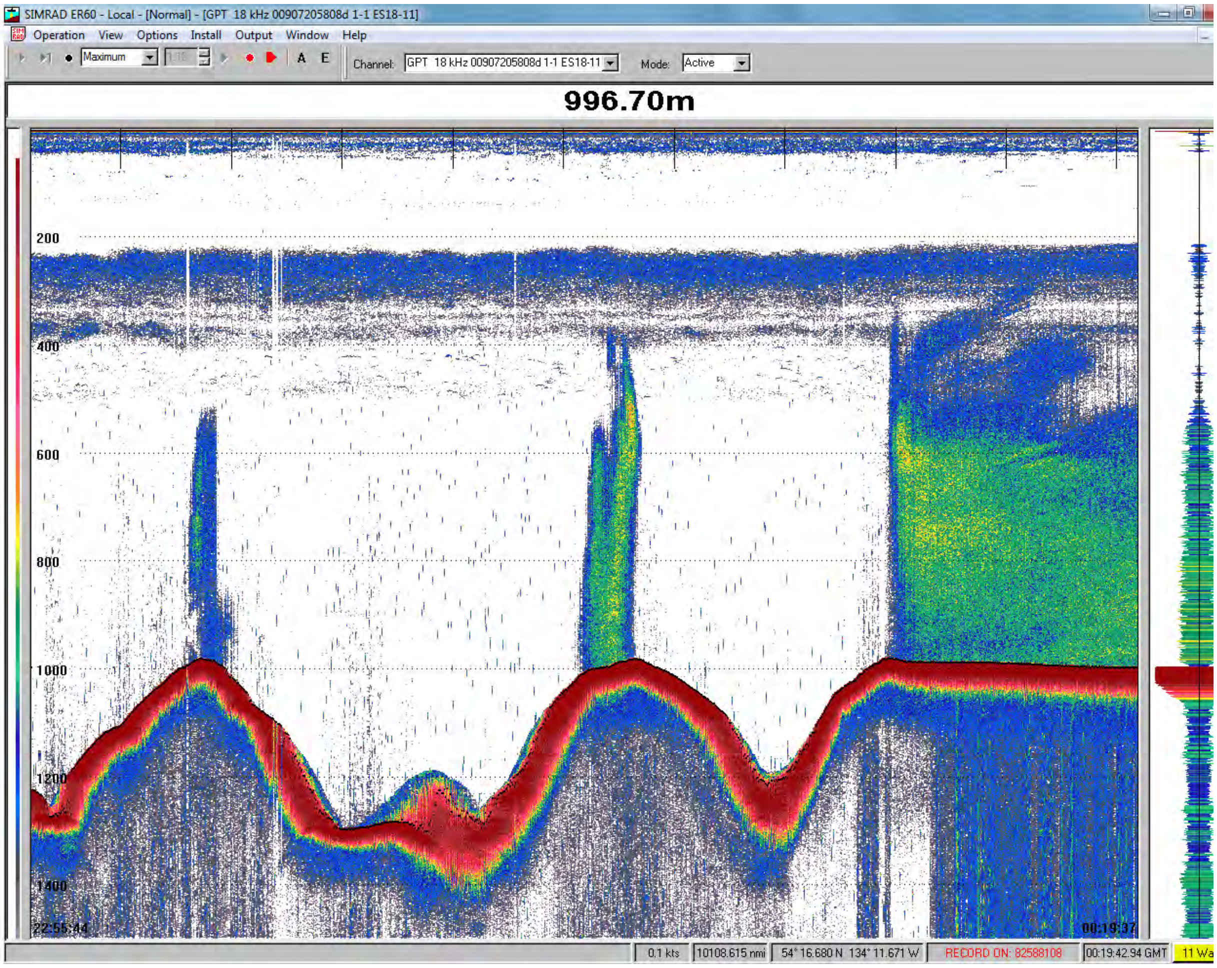
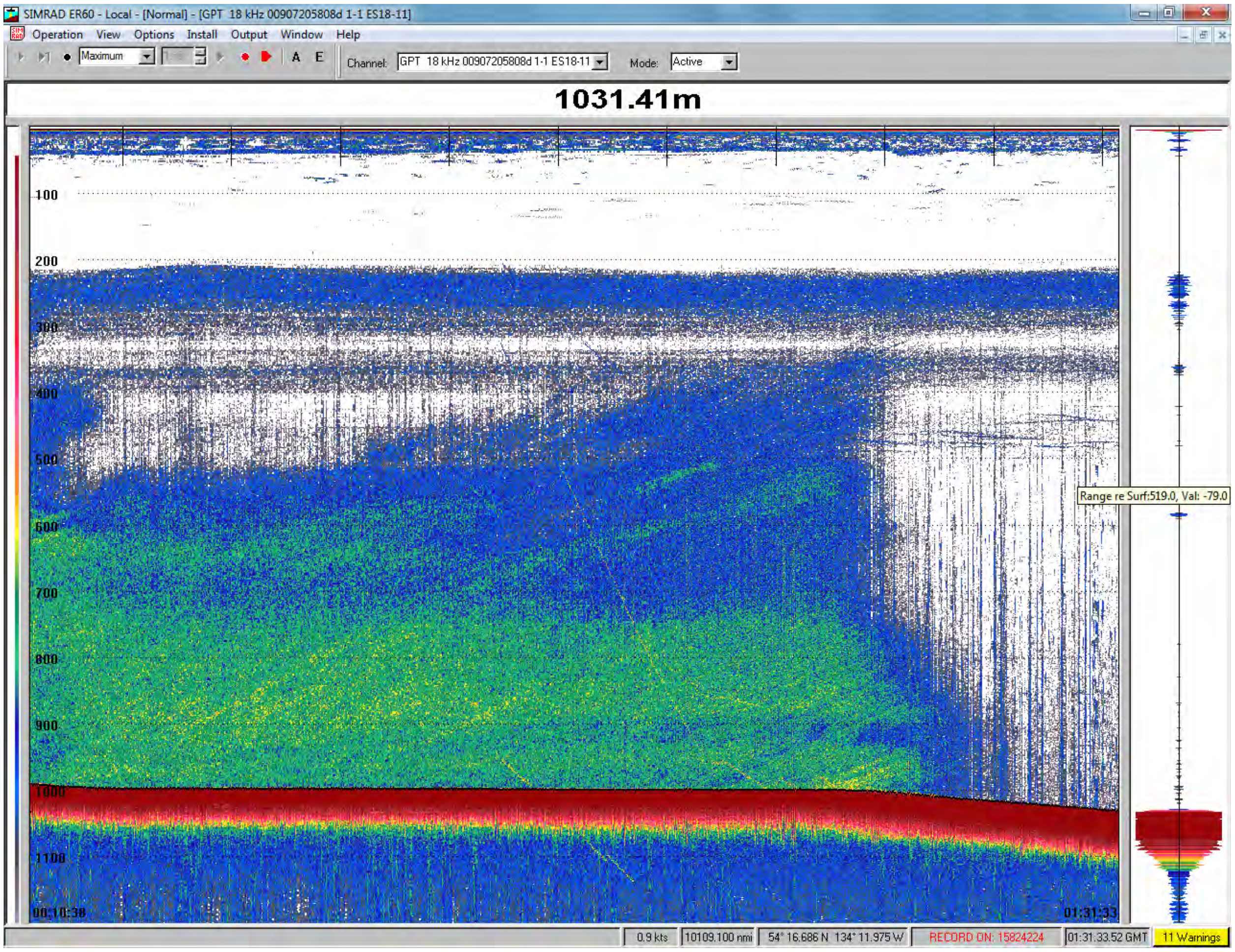
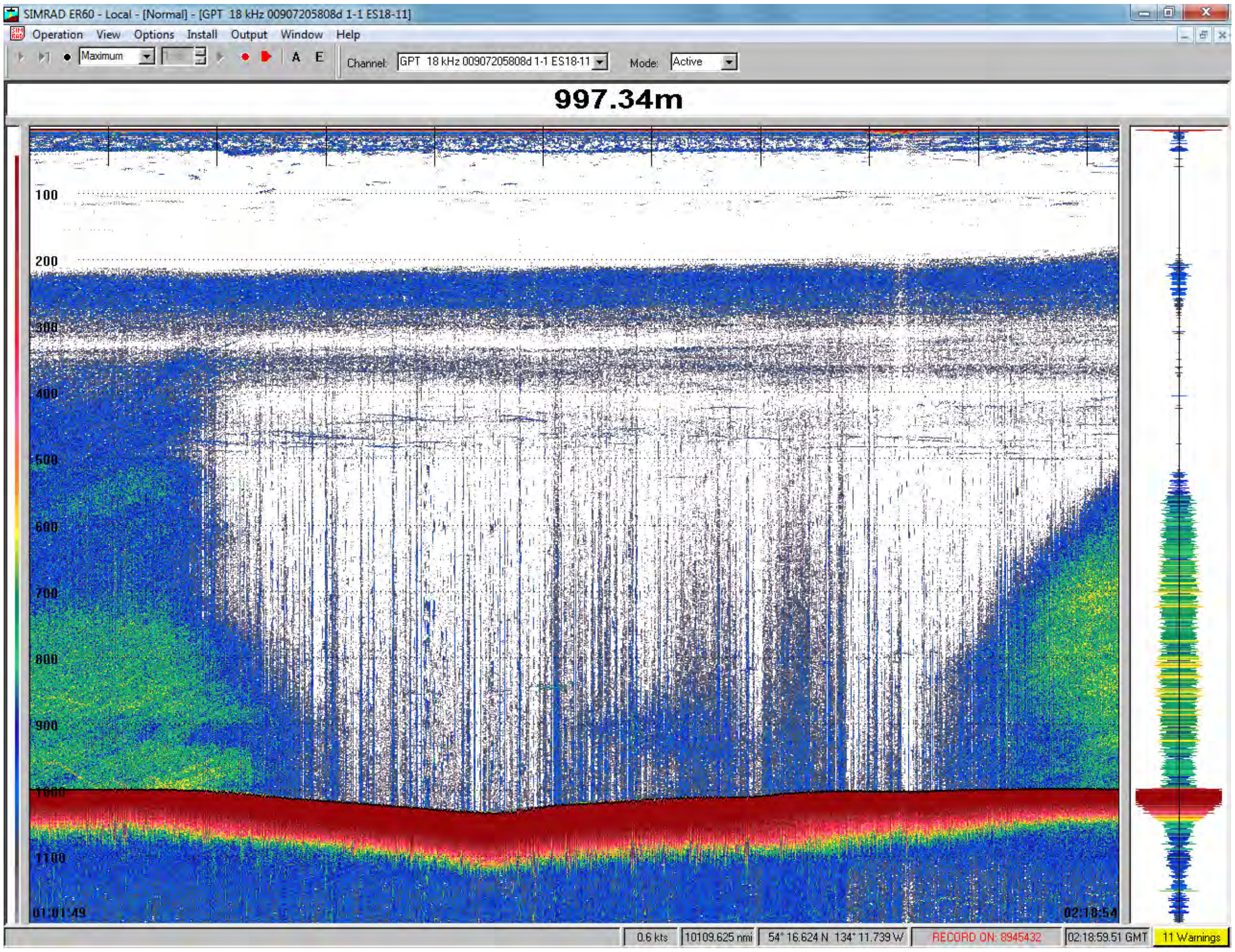
Operation View Options Install Output Window Help
Maximum
A E
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
1111.45m
200
400
600
800
1000
1200
1400
22:25:51
23:48:37
4.7 kts
10107.255 nmi
54° 17.092 N 134° 10.617 W
RECORD ON: 23847404
23:48:42.62 GMT
11 Warnings


SIMRAD ER60 - Local - [Normal] - [GPT 18 kHz 00907205808d 1-1 ES18-11]
Operation View Options Install Output Window Help
Maximum
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
996.70m
200
400
600
800
1000
1200
1400
22:55:44
00:19:37
0.1 kts
10108.615 nmi
54° 16.680 N 134° 11.671 W
RECORD ON: 82588108
00:19:42.94 GMT



SIMRAD ER60 - Local - [Normal] - [GPT 18 kHz 00907205808d 1-1 ES18-11]
Operation View Options Install Output Window Help
Maximum
A E
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
1031.41m
100
200
300
400
500
600
700
800
900
1000
1100
Range re Surf:519.0, Val: -79.0
00:10:38
01:31:33
0.9 kts
10109.100 nmi
54° 16.686 N 134° 11.975 W
RECORD ON: 15824224
01:31:33.52 GMT
11 Warnings



SIMRAD ER60 - Local - [Normal] - [GPT 18 kHz 00907205808d 1-1 ES18-11]
Operation View Options Install Output Window Help
Maximum
A E
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
997.34m
100
200
300
400
500
600
700
800
900
1000
1100
01:01:49
02:18:54
0.6 kts
10109.625 nmi
54° 16.624 N 134° 11.739 W
RECORD ON: 8945432
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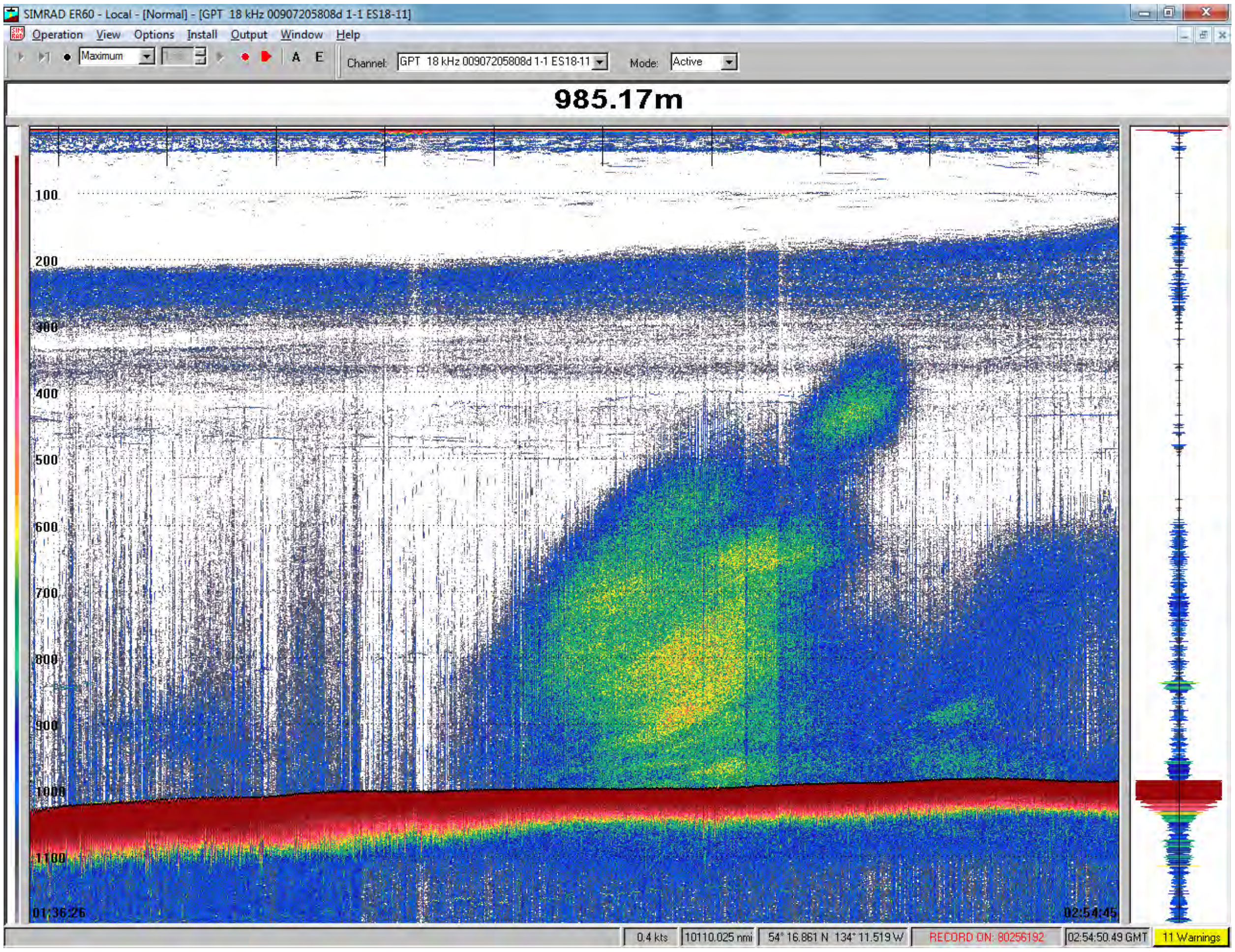
11 Warnings


SIMRAD ER60 - Local - [Normal] - [GPT 18 kHz 00907205808d 1-1 ES18-11]
Operation View Options Install Output Window Help
Maximum
A E
Channel:
GPT 18 kHz 00907205808d 1-1 ES18-11
Mode:
Active
985.17m
100
200
300
400
500
600
700
800
900
1000
1100
01:36:26
02:54:45
0.4 kts
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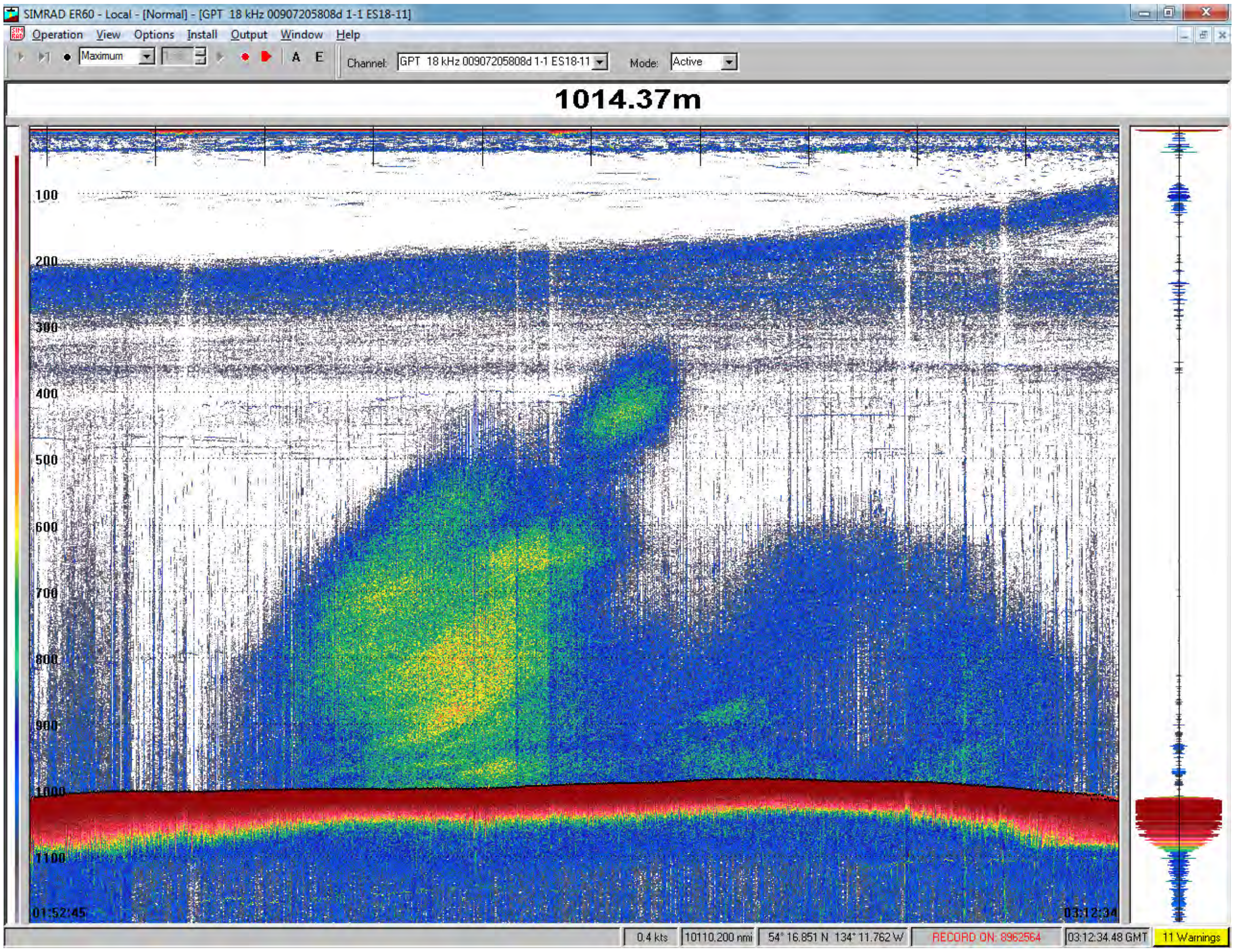
RECORD ON: 80256192
02:54:50.49 GMT
11 Warnings


SIMRAD ER60 - Local - [Normal] - [GPT 18 kHz 00907205808d 1-1 ES18-11]
Operation View Options Install Output Window Help
Maximum
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
1014.37m
100
200
300
400
500
600
700
800
900
1000
1100
01:52:45
03:12:34
0.4 kts
10110.200 nmi
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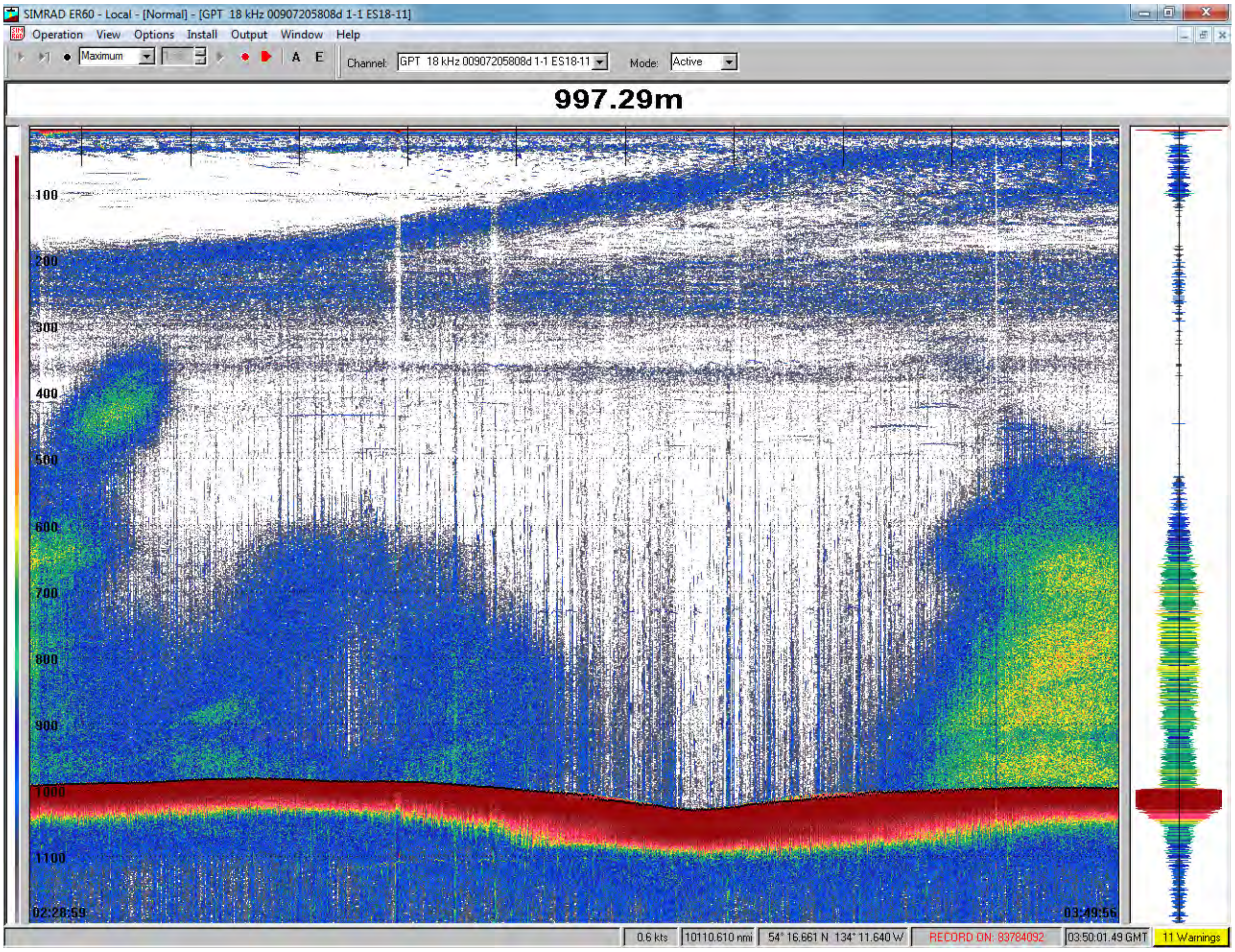
03:12:34.48 GMT
11 Warnings


SIMRAD ER60 - Local - [Normal] - [GPT 18 kHz 00907205808d 1-1 ES18-11]
Operation View Options Install Output Window Help
Maximum
Channel: GPT 18 kHz 00907205808d 1-1 ES18-11
Mode: Active
997.29m
100
200
300
400
500
600
700
800
900
1000
1100
02:28:59
03:49:56
0.6 kts
10110.610 nmi
54° 16.661 N 134° 11.640 W
RECORD ON: 83784092
03:50:01.49 GMT
11 Warnings

3.5 kHz Line Log

Julian Day	Time (GMT)	Latitude	Longitude	Line Start/End
260	0232	48.747821	-123.331238	001
261	1301	51.929452	-131.278849	001
261	1301	51.929452	-131.278849	002
262	0149	51.980419	-131.250784	002
262	0149	51.980419	-131.250784	003
262	0630	52.197284	-131.592844	003
262	0652	52.179572	-131.634266	004
262	0931	52.488836	-131.982680	004
262	0937	52.502916	-131.998866	005
262	0942	52.513375	-132.011407	005
262	0942	52.513375	-132.011407	006
262	1342	53.025188	-132.606258	006
262	1346	53.030320	-132.620248	007
262	1425	53.080176	-132.759704	007
262	1425	53.080176	-132.759704	008
262	1634	53.089713	-132.774719	008
263	0013	53.105328	-132.704560	009
263	0404	53.167781	-132.820814	009
263	0407	53.169004	-132.823751	010
263	0600	53.133864	-132.787821	010
263	0628	53.165774	-132.826062	011
263	0730	53.100665	-132.751001	011
263	0741	53.087588	-132.735656	012
263	0830	53.111936	-132.706646	012
263	0900	53.134744	-132.666789	013
263	1030	53.114372	-132.735345	013
263	1103	53.143182	-132.675019	014
263	1230	53.115725	-132.757017	014
263	1307	53.149073	-132.685262	015
263	1417	53.104189	-132.791758	015
264	0249	53.194167	-132.856333	016
264	0342	53.100500	-132.735500	016
264	0343	53.099500	-132.734333	017
264	0440	53.091167	-132.737833	0017
264	0441	53.093000	-132.739500	0018
264	0550	53.244000	-132.875333	0018
264	0552	53.246333	-132.877667	0019

264	0730	53.255667	-132.886333	0019
264	0820	53.226000	-132.971333	0020
264	0930	53.208833	-132.951500	0020
264	1001	53.181167	-132.938000	0021
264	1200	53.186167	-132.931167	0021
264	1213	53.168833	-132.929000	0022
264	1324	53.266333	-132.936333	0022
265	0458	53.493000	-133.086000	023
265	0633	53.478500	-133.148167	023
265	0701	53.500167	-133.090500	024
265	0900	53.495333	-133.159667	024
265	0922	53.513667	-133.110667	025
265	1130	53.517333	-133.158167	025
265	1146	53.529162	-133.127778	026
265	1532	53.529833	-133.295167	026
265	2329	53.483167	-133.142500	027
266	0012	53.451963	-133.197157	027
266	0054	53.513667	-133.216167	028
266	0231	53.648333	-133.257167	028
266	0301	53.704710	-133.342630	029
266	0431	53.853833	-133.651333	029
266	0500	53.897517	-133.746527	030
266	0631	54.027000	-134.053500	030
266	0652	54.055000	-134.127000	031
266	0830	54.128667	-133.929500	031
266	0900	54.151667	-133.870167	032
266	1101	54.197167	-133.863333	032
266	1130	54.195333	-133.928833	033
266	1411	54.189167	-134.281833	033
266	1414	54.192333	-134.284000	034
266	1530	54.285500	-134.216667	034
266	2157	54.195000	-133.956667	035
266	2350	54.279667	-134.192833	035
267	0422	54.279833	-134.195833	036
267	0600	54.373333	-134.076167	036
267	0630	54.403167	-134.028500	037
267	0730	54.460667	-133.936833	037
267	0759	54.487667	-133.895167	038
267	0930	54.436333	-134.104333	038
267	1000	54.419167	-134.172667	039
267	1130	54.367602	-134.386227	039
267	1159	54.352167	-134.453333	040
267	1400	54.368000	-134.346833	040

267	1404	54.362000	-134.345667	041
267	1451	54.278833	-134.194500	041
268	0234	54.276167	-134.179500	042
268	0434	54.558000	-133.983000	042
268	0451	54.587000	-133.942833	043
268	0631	54.614000	-133.504500	043
268	0655	54.620333	-133.402667	044
268	0830	54.806167	-133.287167	044
268	0852	54.872333	-133.289000	045
268	0930	54.971333	-133.376833	045
268	0940	54.996333	-133.398167	046
268	1100	55.112000	-133.480500	046
268	1134	55.159000	-133.513000	047
268	1200	55.157333	-133.461167	047
268	1227	55.152550	-133.394635	048
268	1400	55.096167	-133.595167	048
268	1435	55.060500	-133.584333	049
268	1601	55.110333	-133.390667	049
268	1638	55.074667	-133.376833	050
268	1859	55.097500	-133.380500	050

APPENDIX II

Core Photos, Description, And Logs

See attached 2015004 PGC Cores PDF

Stn	Sept.	Time	Setting	Length	description	min dens
1	18	1315	slide at base of fault scarp	106	64 cm sand over 28 cm clay over 14 cm sand.	1.6
2	18	1550	in thalweg of channel	230	low susc, but the higher susc in the top 80 cm. 13 minor peaks in susc and dens = sand layers? The up high susc part has lower density on average. At subsample taken at 111 cm: glass spicules and forams.	1.7
3	18	1810	on upper bajada east of fault scarp	245	alternating sand, clay. Turbidite record? Strong peak at 158 cm. Even higher susc peak in TWC at 105 cm.	1.7
4	19	1100	in channel that connects displaced Cartwright canyon	0	core catcher jammed with gravels, well rounded, and fractured volcanic-like rock,suggestive of a channel, possibly a sill, with volcanic bedrock	
5	19	1200	Cartwright canyon	40	4 density-susc peaks. old channel deposited on mud?	2
6	19	1430	lower Cartwright canyon, closest flat area to fault and below retrogressive slumps	46	mud with 5 subtle sand layers.	2
7	19	1500		83	sand over mud. 9 highish dens-susc layers.	1.8
8	19	1700		0	Very short core with sand	
9	20	800	upper reaches of small gully 1	135	short dense section caught in upper barrel. Then a longer sand-mud section at bottom of lower barrel. Clay got sucked out the core catcher? A few dens-susc peaks, but mostly gentle compaction increases in dens-susc.	2.1
10	20	1000	inner levee of Cartwright canyon	0	little sediment (sand) recovery	
11	20	1130	southern failure scarp of channel 2 mouth.	0	little penetration with stiff mud in core catcher	
12	20	13:30	confluence of two channels just south of Cartwright canyon.		24 cm of sand over 24 cm plus core catcher hard dense clay. Subtle high dens-susc layers.	2
13	20	1520	first gully west of Rift valley opening on west side of fault.	0	a few pebbles in core catcher	
14	20	1930	CAMERA: along Queen Charlotte Fault rift.			
15	21	800	Pull apart basin	33	interbeddedgravel and clay. strange anticorelation between dens and susc.	2
16	21	905	in subtle gully on north side of slide.	165	loose sand on top and mud below. Very high dens-susc layer at 65 cm. 10 high dens-susc layers.	2
17	21	1010	base of headwall of northern slump head, in small slump deposit.	277	20 cm unconsolidated sand on top with190cm stiff clay below, on 70 cm sand? ~11 sandy layers within clay. Could be turbidite sequence.	1.9

18	21	1055	head scarp of slide where possible slide plane is covered with thin layer of sediment, at southern margin of pockmark field	0	no core, just very dense stiff mud in core catcher, pilot core shows dark chunky clay over lighter less dense clay – could be slide plane	
19	21	1300	at base of gullied slump apron of slide, possible slide plane	123	25 cm layer of sand overlying 8cm clean clay, over 85 cm of clay with sand layers.	1.9
20	21	1430	base of leading edge of large glide block of slide	257	clay, brown to gray clay, perhaps Holocene over Pleistocene. Possibly correlatable with Stn 19 features, but lower dens-susc and more spread out in depth.	1.7
21	21	14:30	very distal edge of slide.	222	with thin cover of fine sand over clay with ~15 sand layers.	2
22	21	18:45		0	80 sand grains wiped off the core catcher!	
23	22	950	at apparent north end of terrace where terrace surface meets the eastern slope, NE of pull-apart basin where fault steps to the right and possibly changes from transtension to transpression (a right-stepping fault).	40	stiff mud with thin layer of sand on top. Reconstituted section 2 from core catcher. Monster high susceptibility, from Masset volcanics?	1.8
24	22	1110	north of the apparent pull-apart basin on the southern flank of the transpressional ridge, north of multibeam coverage.		sand in core catcher	
25	22	1310	floor of pull-apart basin	56	15 cm unconsolidated silty sand top and 40 cm clay bottom with 3 high susc layers. High mag susc.	1.6
26	22	1445	slump on west side of pull-apart basin.	92	sand on top and clay below. 10 or 11 beautiful high dens-susc layers.	1.6
27	22	1615	slump on east side of pull-apart basin	101	sand on top and clay below. 10 or 11 beautiful high dens-susc layers. Apparent excellent correlation between either side of the rift.	1.7
28	23	1110	slump near upper head scarp of large landslide near Dickson Entrance		sand layer over clay. Much lower susceptibility - no influence from Haida Gwaii. Uniform high dens-susc layer from 30 to 45 cm depth. Several subtle dens-susc anomalies.	1.6
29	23	1245	sediment pond in possible conjugate or horsetail splay fault depression	35	silty mud. 25 cm Low susc over 10 cm high susc.	2
30	23	1450	sediment pond in main fault trace.	66	section 2 reconstituted from clay in the core catcher. 38 cm sand above 20 cm clay.	1.8
31	23	2100	CAMERA: volcano / vent			

32	24	945	IKU grab (P180). mud/clay, gravel, clams & mussels, and cemented mud, strong smell of H2S.	2x 20	2 push cores. Top 10 cm slightly higher dense-susc.	1.9
33	24	1045	IKU grab (P88). mud with some gravel, little volcanics	20	push core. Top 10 cm slightly higher dense-susc.	1.9
34	24	1320	IKU grab (P309). completely filled and overflowing with mud and sparse gravels, few pebbles and cobbles along with one angular clast of concoidal fractured basaltic-looking rock.			
35	24	1500	IKU grab (P238). primarily empty with the exception of a few (12 or so) clean cobbles and pebbles consisting of allocthonous plutonic clasts, carbonate tubes, phosphatically cemented angular sandstone and one angular volcanic cobble.			
36	24	1635	IKU grab (P90). mud and small sub-rounded to sub-angular boulders, cobble pebbles and gravel. Mixed lithologies no real immediate evidence of lava.			
37	24	1900	CAMERA: volcano / vent flank			
38	25	1245	just east of NW-SE trending fault in relatively thick sediments that thin eastward.	380	Extremely low and flat profile. Possible variations visible in mud on enlargement.	1.2
39	25	1345	in northern end of shear zone, thin overlying sediment wedge that overlies thick sediment pond.	430	very low and flat, but bottoming on rock and gravel, with 70 cm fining-up sequence.	1.3
40	25	1450	south end of NW-SE trending fault in sediment filed that lap westward onto fault.	460	Extremely low and flat profile. Possible variations visible in mud on enlargement.	1.3
41	25	1600	near granite in subtle fault zone east of the shear zone; very narrow target.	370	Minor fining-up seuence in top 110 cm. Four large FUS down to 220 cm. Minor variations below.	1.4
42	25	1725	south of Felix MBES map, in sediment pond over fault that extends northward toward Cape Felix.	380	Abrupt fining-up sequence at 175 cm, for 40 cm.	1.3

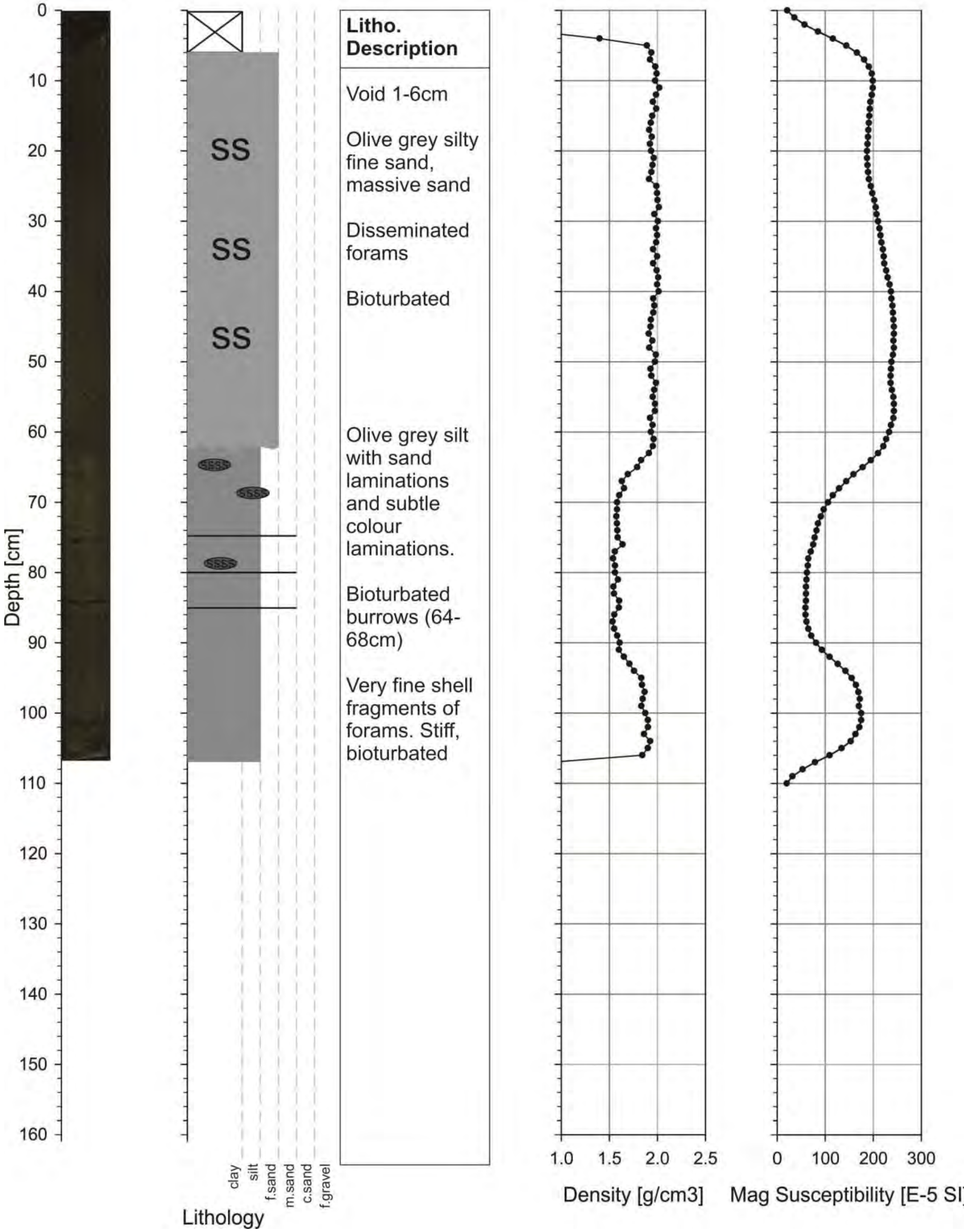
max dens	min susc E-5	max susc E-5
2	60	250
2.1	20	170
2.5	20	270 (twc 530)
2.4	150	210
2.1	200	240
2.2	90	260
2.3	180	330
2.3	40	230
2.4	260	360
2.4	210	680
2.4	200	400

2.3	230	440
2.2	80	360
2.3	250	410
2.1	500	1180
2.05	350	710
2.1	310	590
2.1	390	560
1.95	40	210
2.4	80	260
2.2	140	260

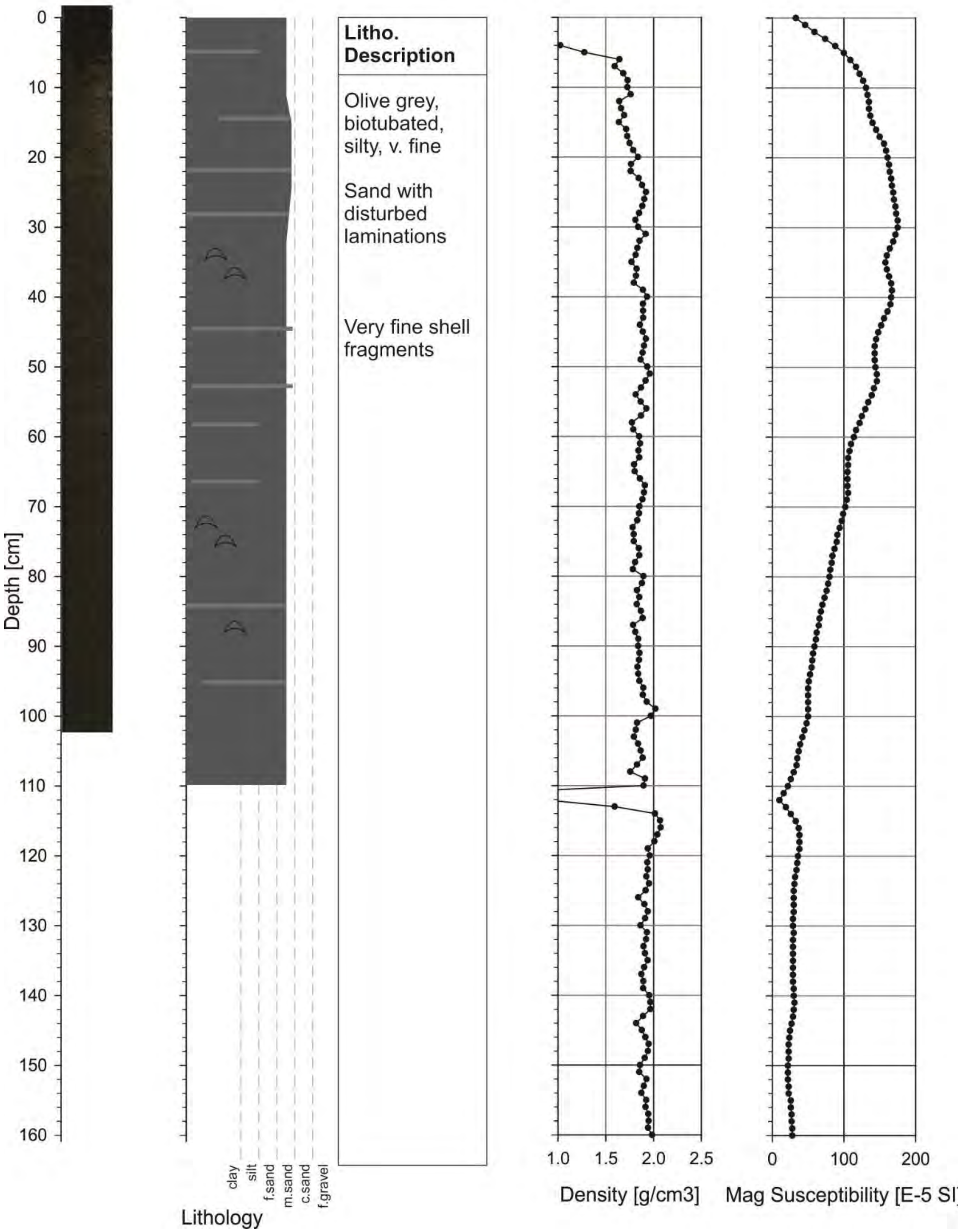
2.4	10	70
2.2	10	70
1.33	1	4
2.2	1	28
1.5	1	5
2.1	10	145
2	4	16

Lab Number	Sample Number	Cruise Number	Station Number	Sample Interval	Material	^{14}C age BP	±
UCIAMS							
167530	201504-02232	2015004PGC	2	232	Shell	14095	35
167531	201504-0371	2015004PGC	3	70-72	Shell	12005	30
167532	201504-0539	2015004PGC	5	38-40	Shell	39080	690
167533	201504-09129	2015004PGC	9	129	Shell	42870	1100
167534	201504-1528	2015004PGC	15	27-29	Shell	21320	80
167535	201504-1631	2015004PGC	16	31	Shell	13450	35
167536	201504-1648	2015004PGC	16	48	Shell	49390	2500
167537	201504-16165	2015004PGC	16	165	Shell	16190	45
167538	201504-1928	2015004PGC	19	27-28	Shell	14110	40
167539	201504-1940	2015004PGC	19	39-41	Shell	13620	35
167540	201504-20109	2015004PGC	20	109	Shell	20980	80
167541	201504-2315	2015004PGC	23	14-16	Shell	13460	35
167544	201504-38340	2015004PGC	38	339-341	Shell	3580	20
167545	201504-39276	2015004PGC	39	275-277	Shell	6500	20
167546	201504-39386	2015004PGC	39	385-387	Shell	10955	25
167547	201504-39412	2015004PGC	39	411-413	Shell	10710	25
167548	201504-4133	2015004PGC	41	33-34	Shell	3825	20
167549	201504-41129	2015004PGC	41	128-130	Shell	7680	20
167550	201504-41146	2015004PGC	41	146	Shell	10690	25
167551	201504-42150	2015004PGC	42	148-151	Shell	10730	25
167552	201504-42171	2015004PGC	42	170-172	Shell	11015	25
167553	201504-42225	2015004PGC	42	224-226	Shell	11505	30
167554	201504-42286	2015004PGC	42	285-288	Shell	11975	30
167555	201504-42361	2015004PGC	42	360-362	Shell	12560	30

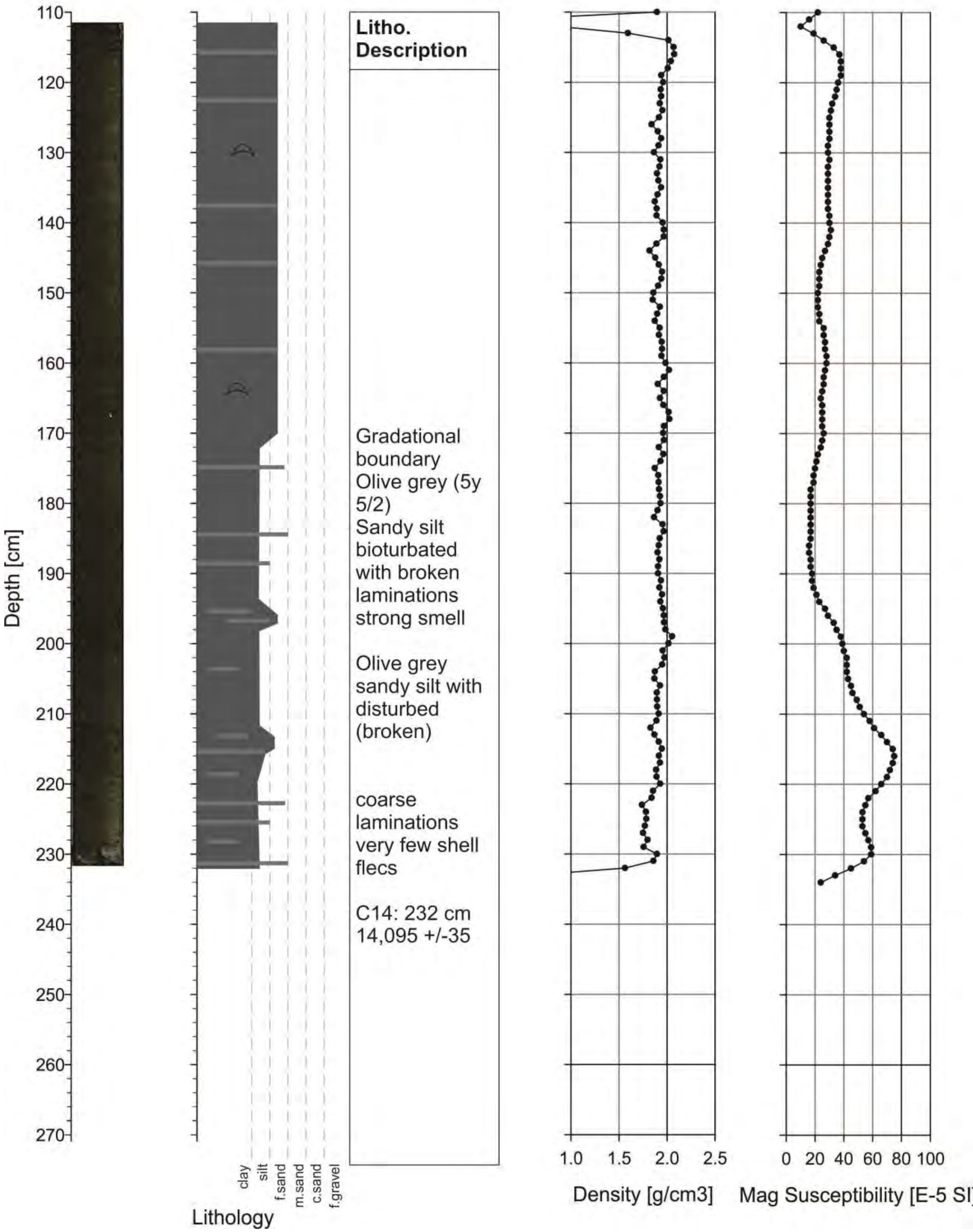
2015004PGC001



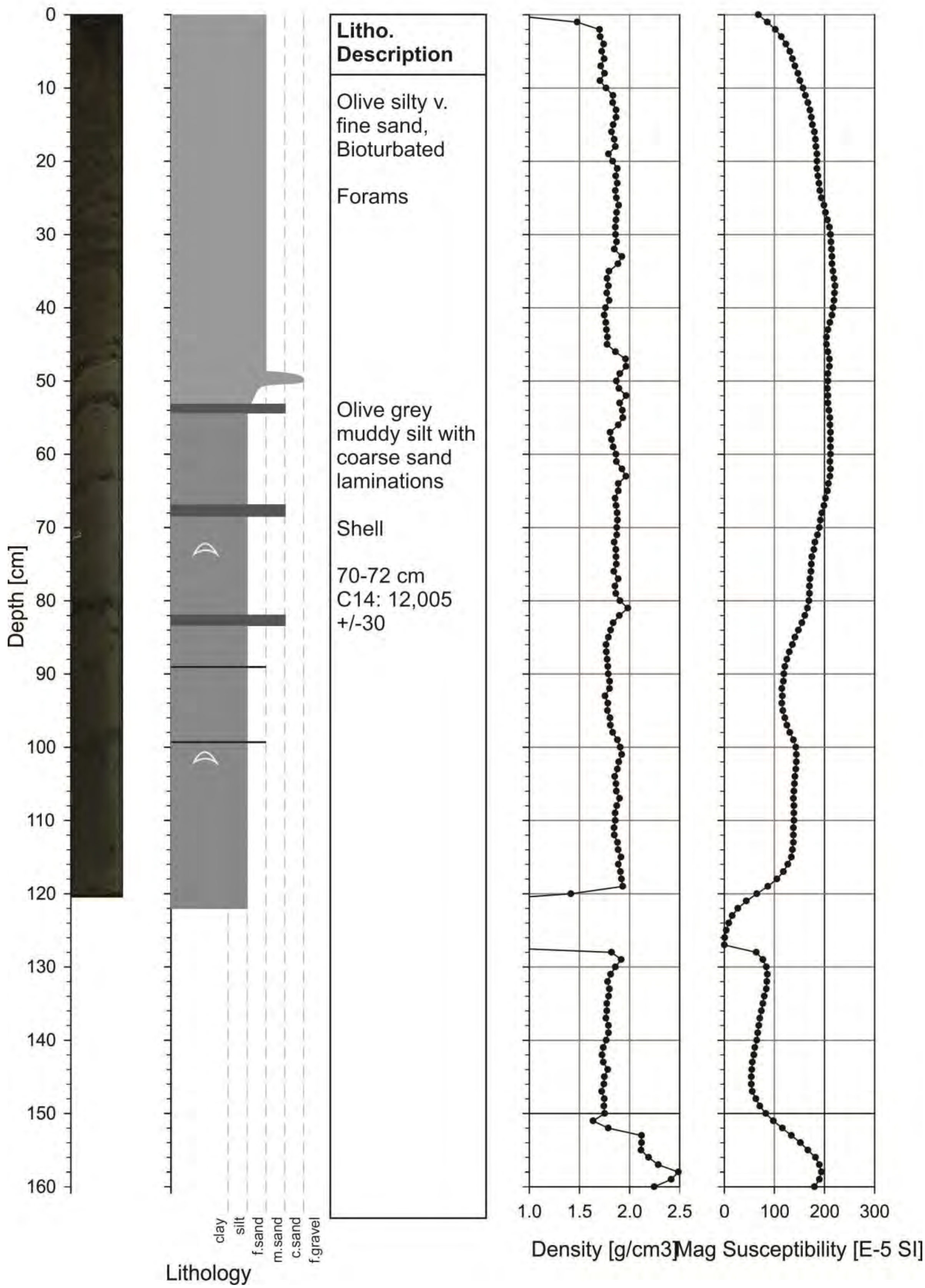
2015004PGC002 - Section 1



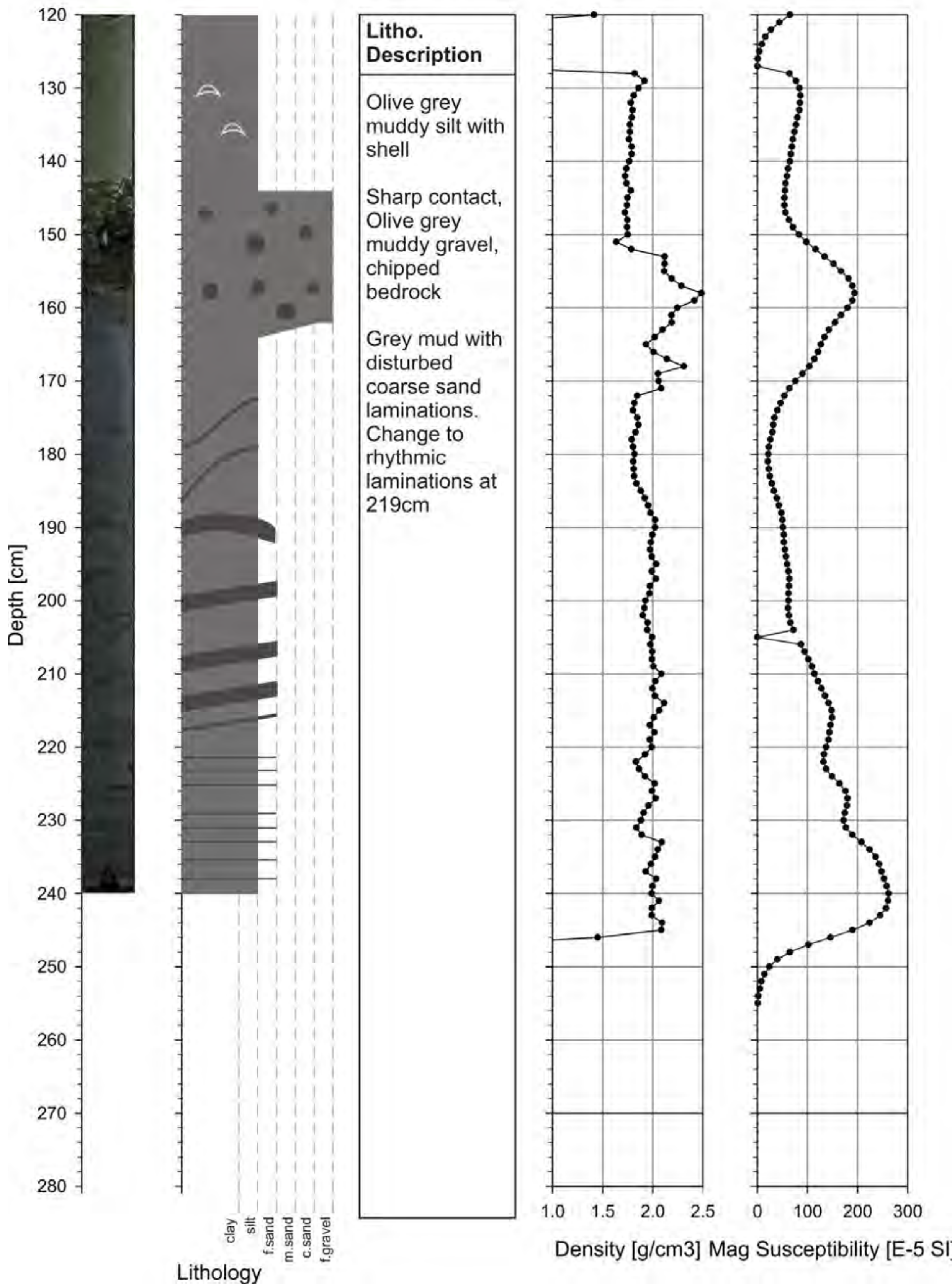
2015004PGC002 - Section 2



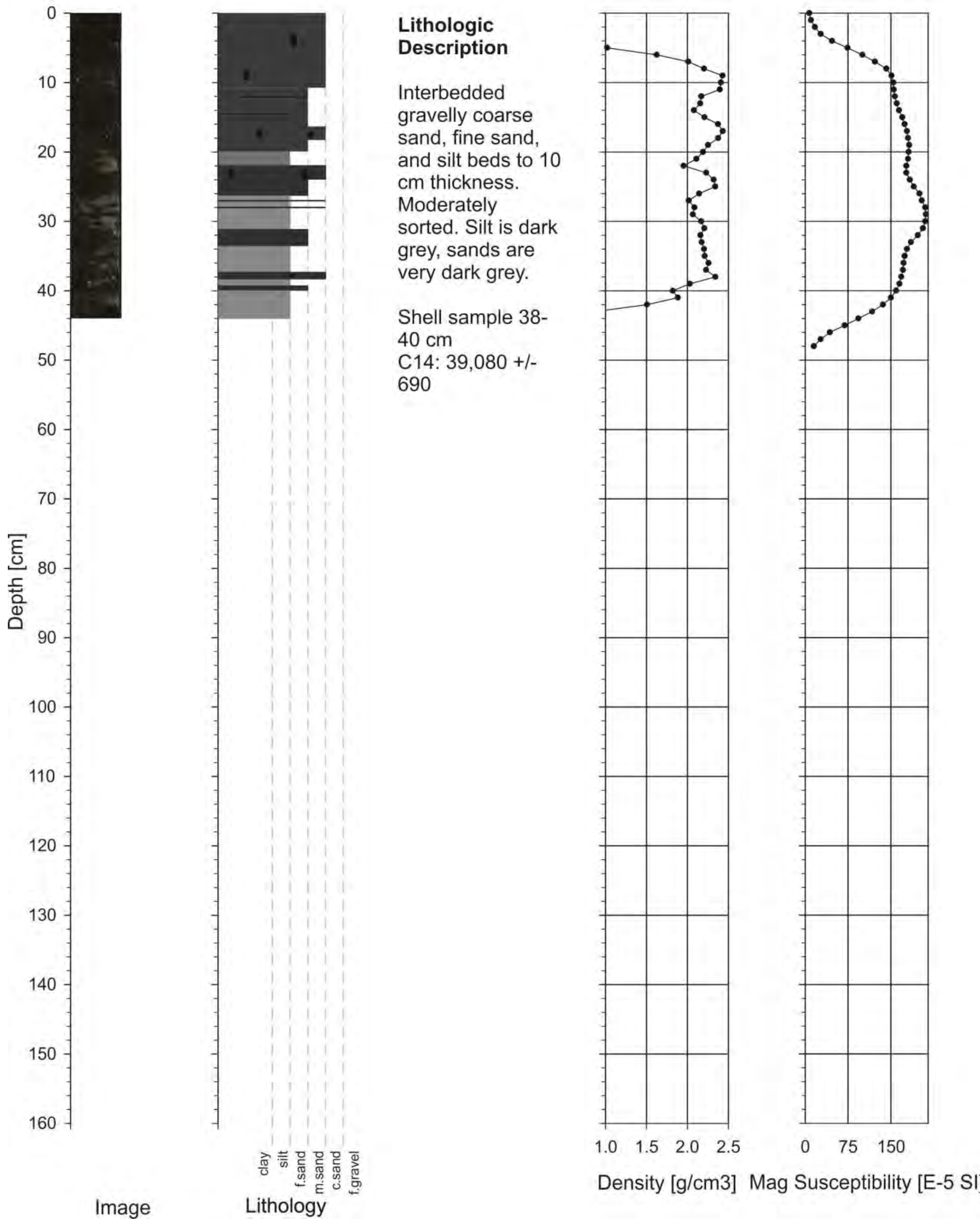
2015004PGC003- Section 01

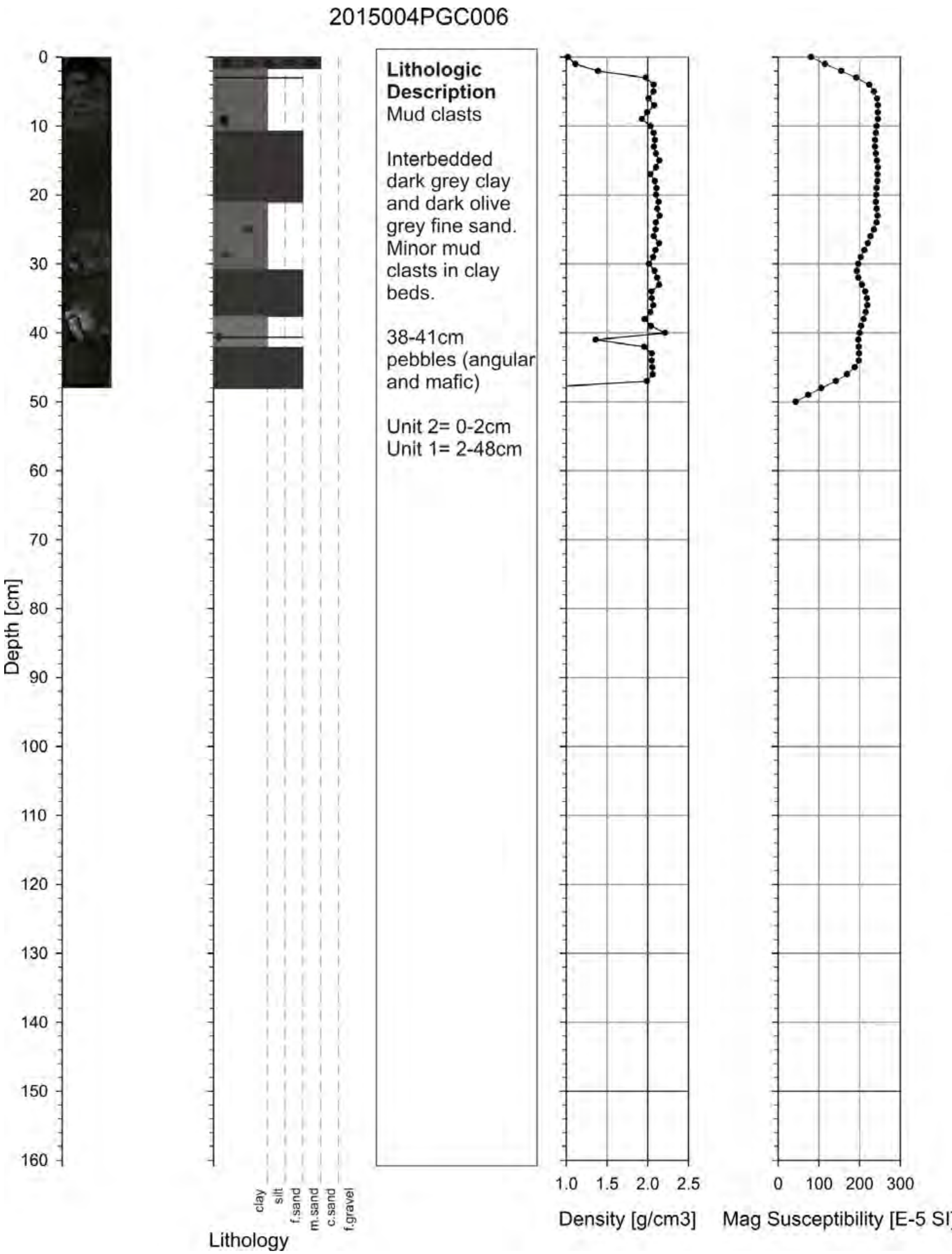


2015004PGC003 - Section 02

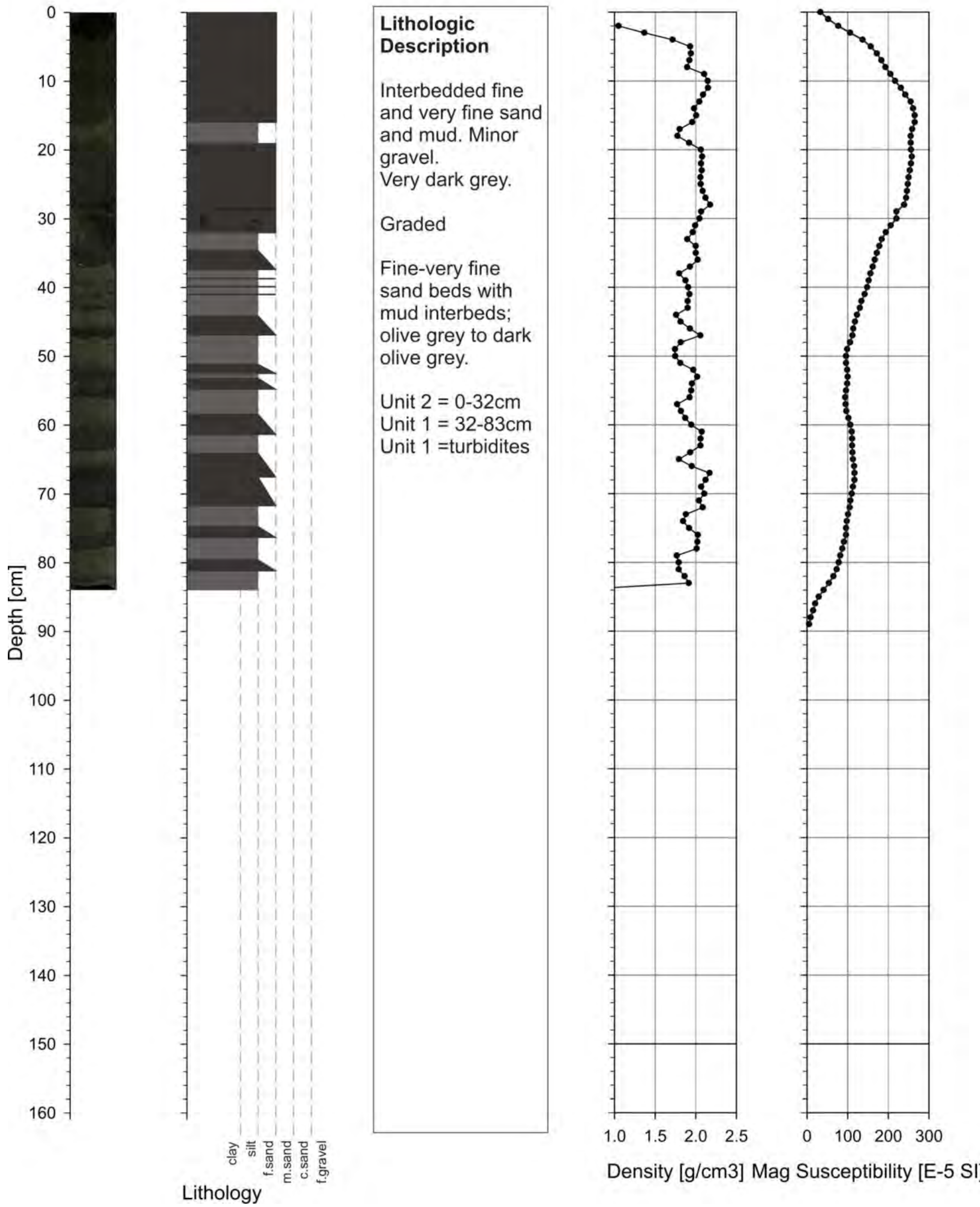


2015004PGC005

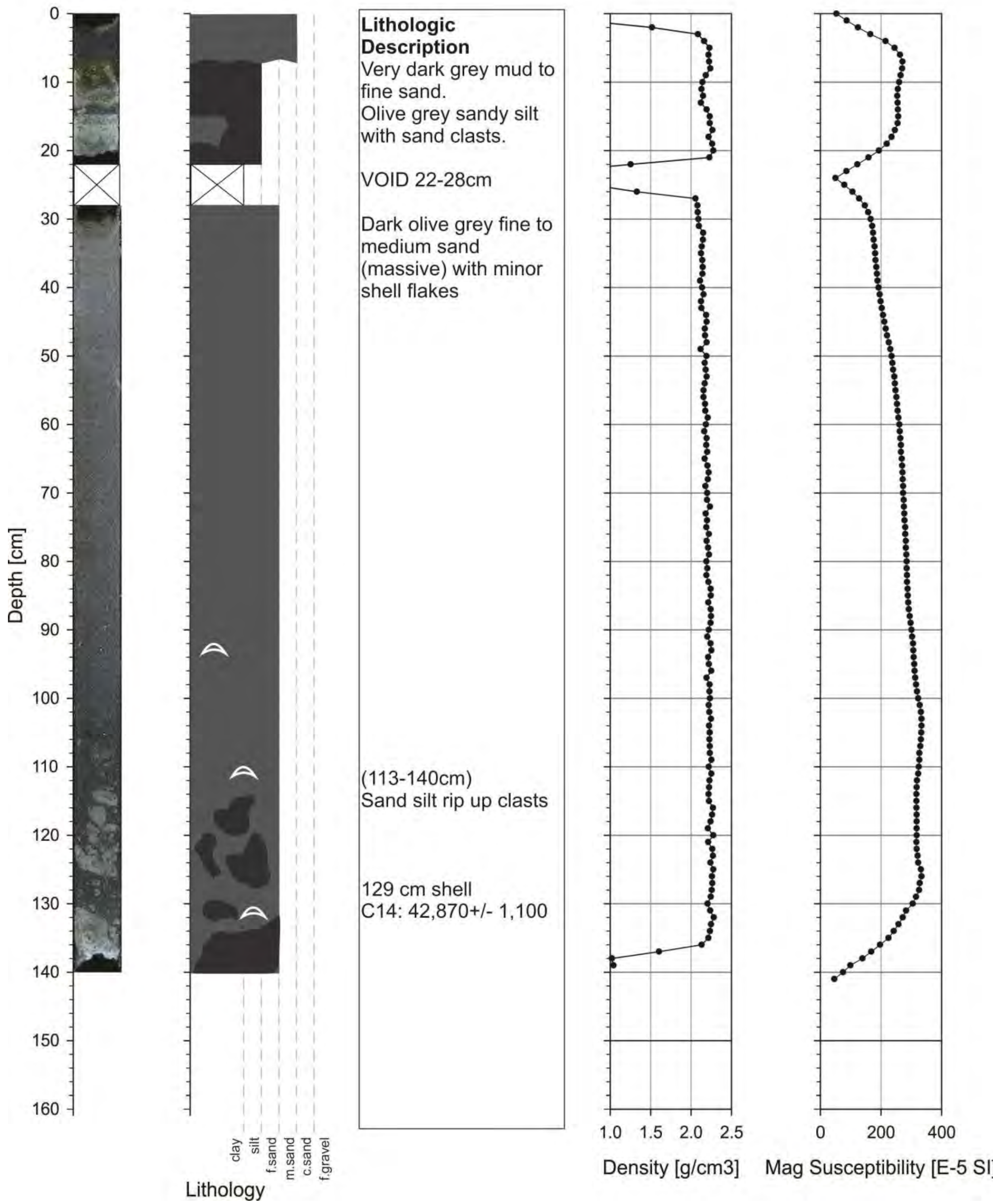



2015004PGC006
Depth [cm]
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
clay
silt
f.sand
m.sand
c.sand
f.gravel
Lithology
Lithologic Description
Mud clasts
Interbedded dark grey clay and dark olive grey fine sand. Minor mud clasts in clay beds.
38-41cm pebbles (angular and mafic)
Unit 2= 0-2cm
Unit 1= 2-48cm
1.0 1.5 2.0 2.5
Density [g/cm3]
0 100 200 300
Mag Susceptibility [E-5 SI]

2015004PGC007



2015004PGC009



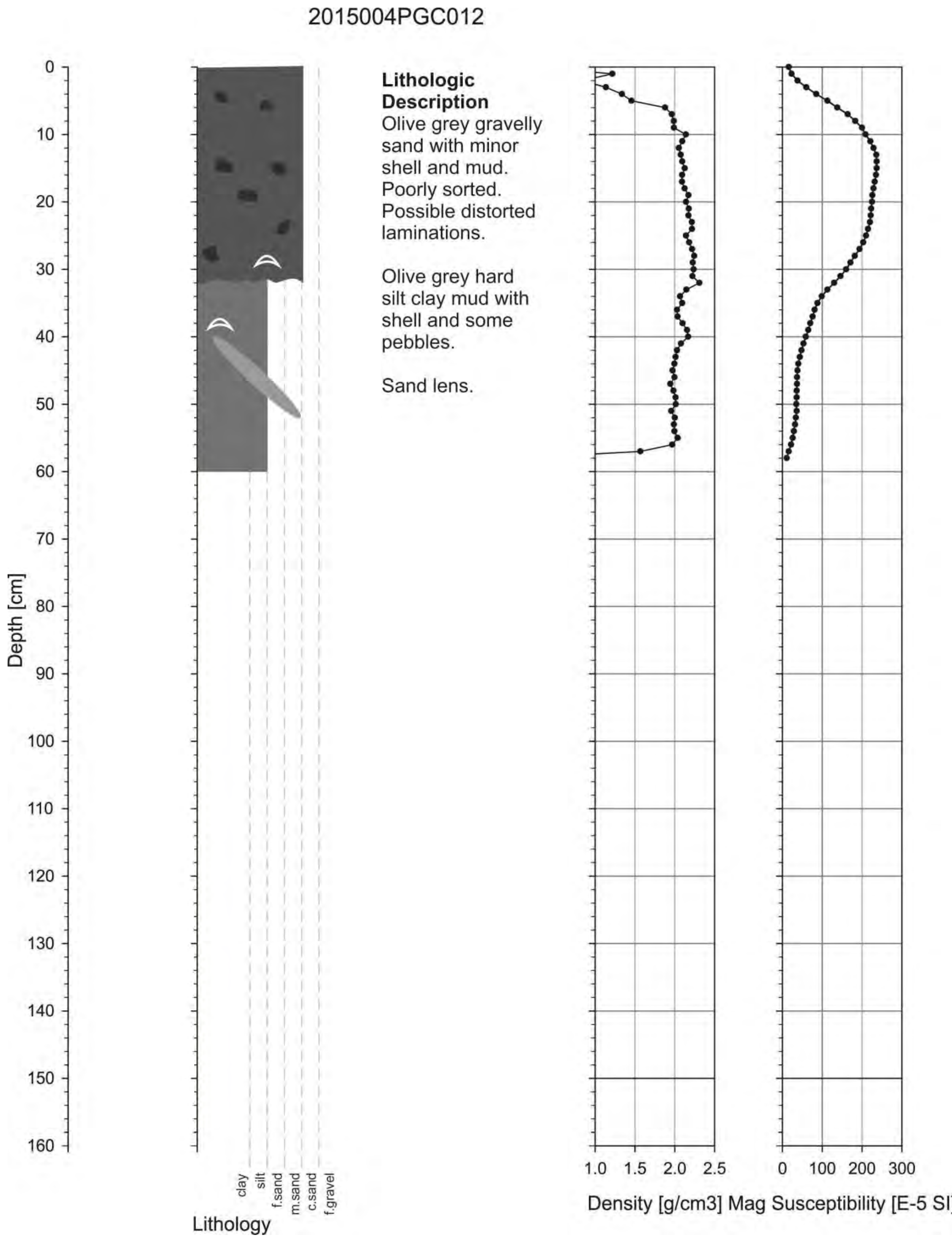
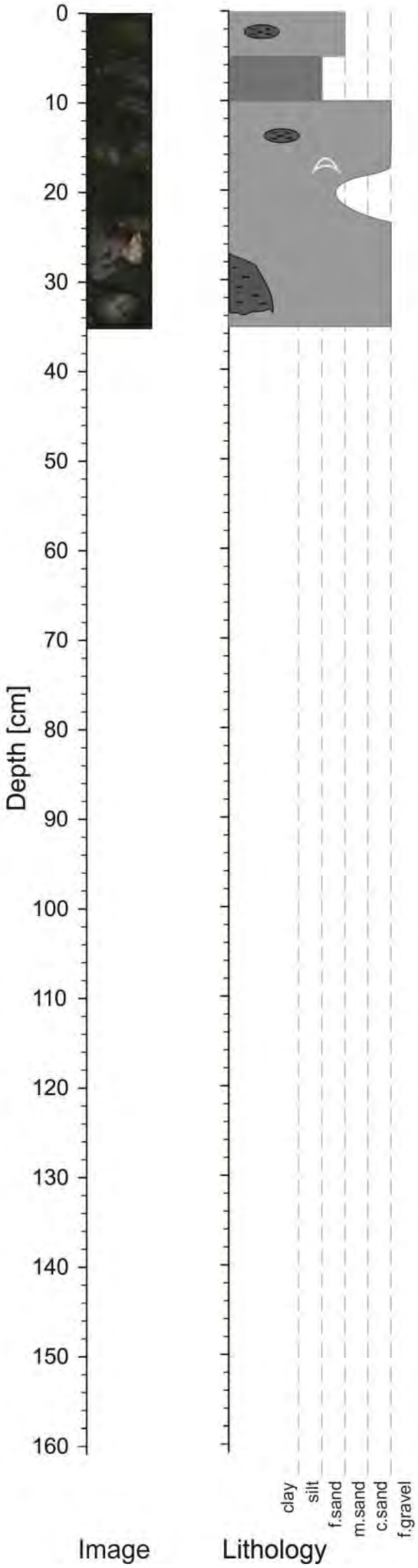

2015004PGC012
Depth [cm]
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
clay
silt
f.sand
m.sand
c.sand
f.gravel
Lithology
Lithologic Description
Olive grey gravelly sand with minor shell and mud. Poorly sorted. Possible distorted laminations.
Olive grey hard silt clay mud with shell and some pebbles.
Sand lens.
1.0 1.5 2.0 2.5
Density [g/cm3]
0 100 200 300
Mag Susceptibility [E-5 SI]

*Image did not have scale attached

2015004PGC015



Litho. Description

Olive grey muddy fine sand with rip up clasts

Hard Clay

Olive grey gravelly sand with hard clay rip up clasts and shell. Gravel very angular.
27 - 29 cm
C14: 21,320 +/-80

Cobble:
31-35cm
bagged

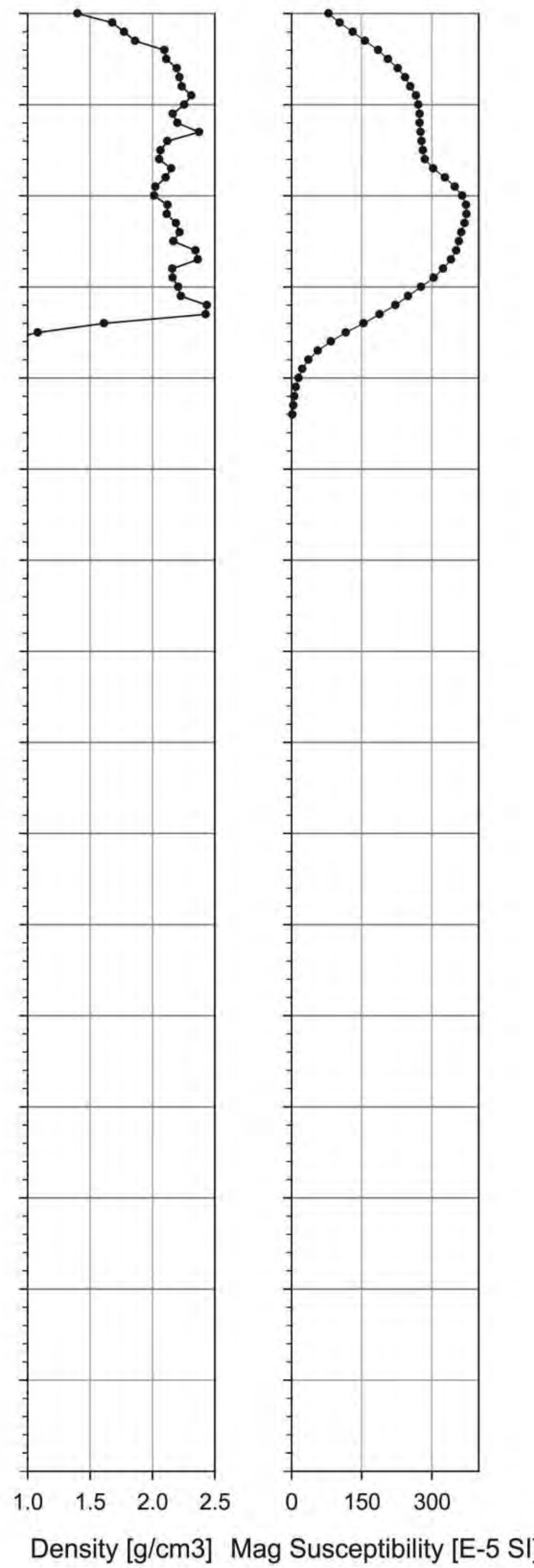
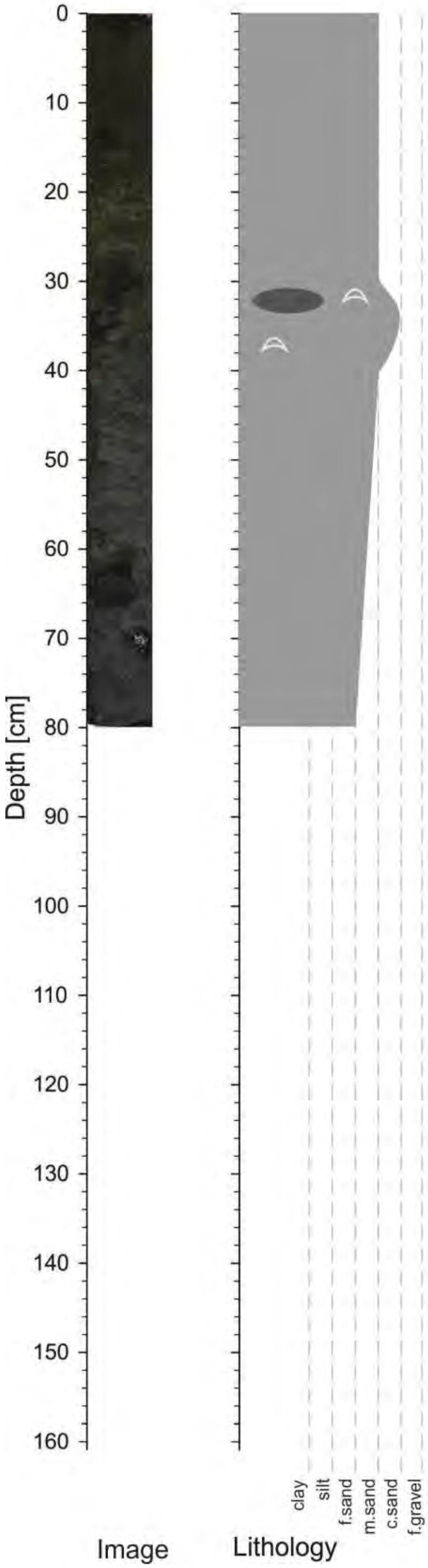


*Image did not have scale attached

2015004PGC016 - Section 01



Litho. Description

Olive grey medium to coarse sand with pebbles and mud (poorly sorted) Forams throughout, shell.

31-35cm, large cobble

Gradual contact. Olive grey sandy mud with shell and sand laminations. Some gravel and cobbles.

More muddy down core.

31 cm
C14: 13,450
+/- 35

40-48 cm
C14: 49,390
+/- 2,500

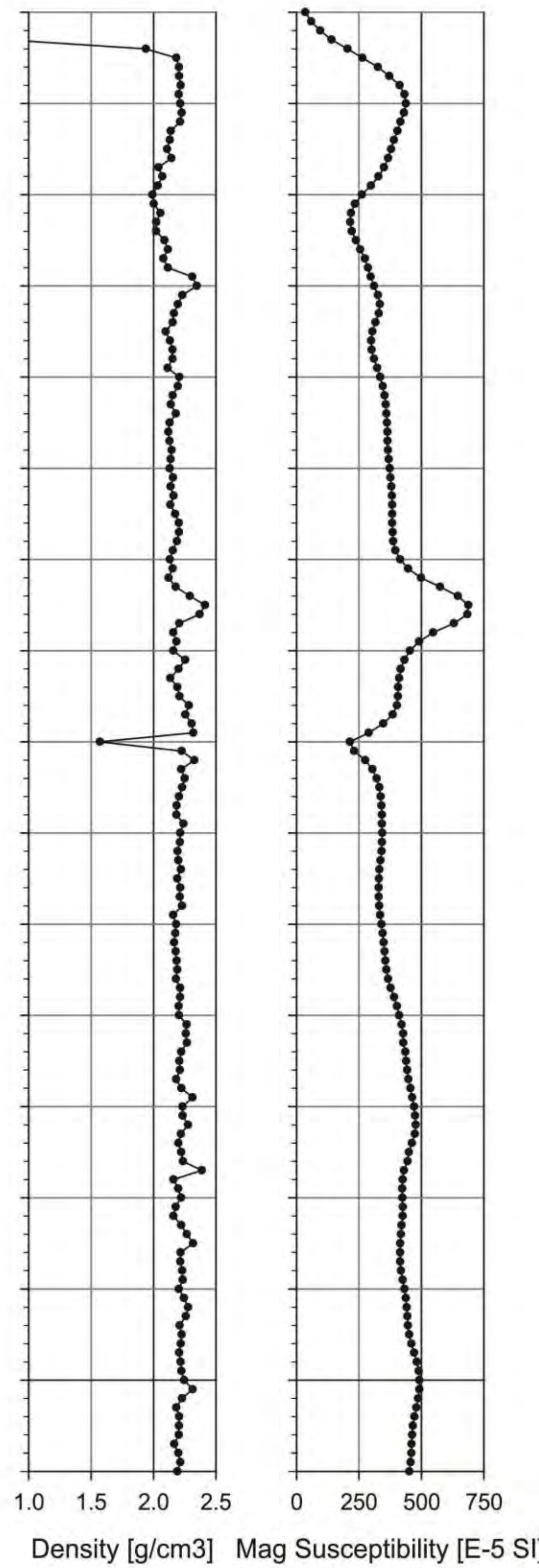
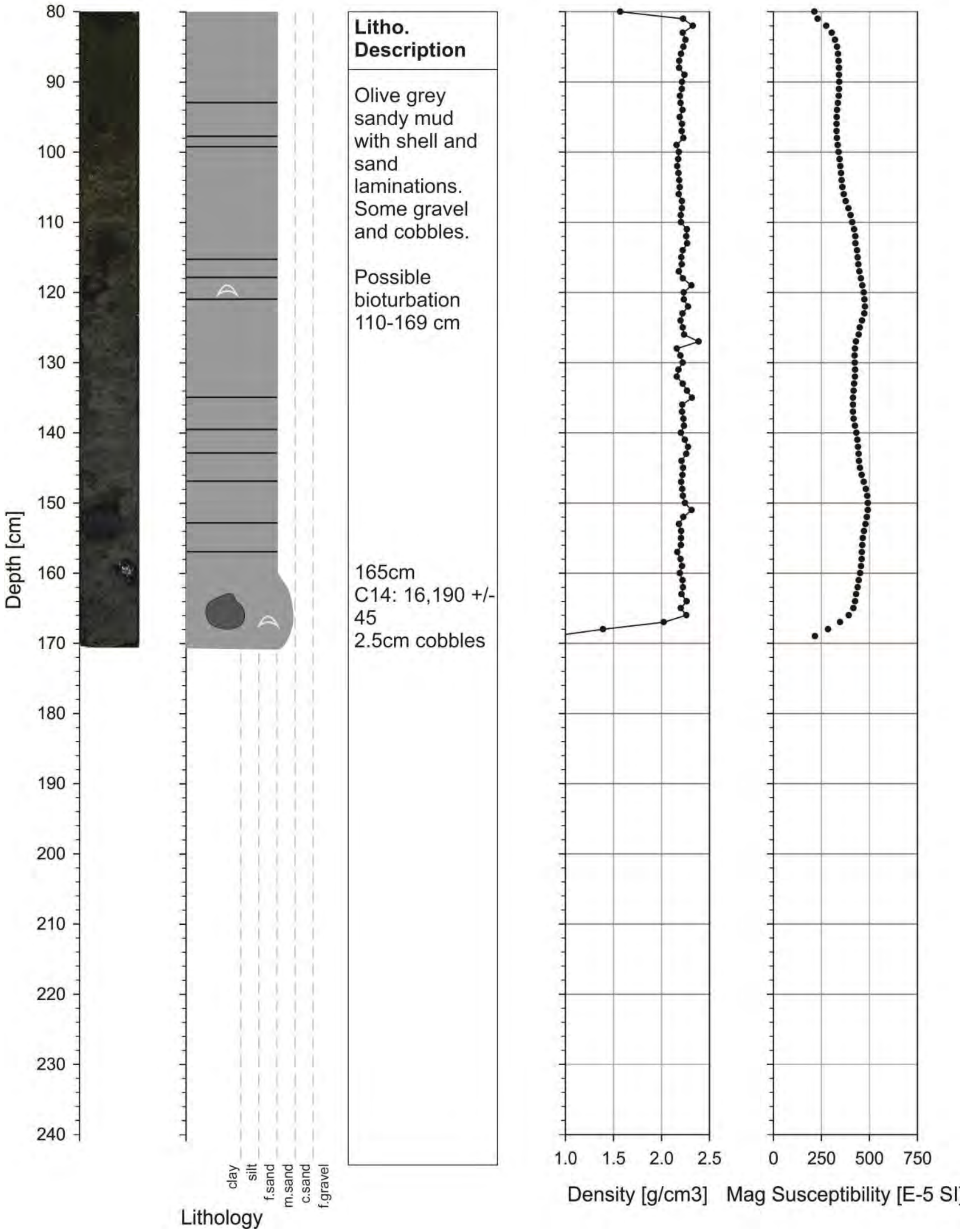
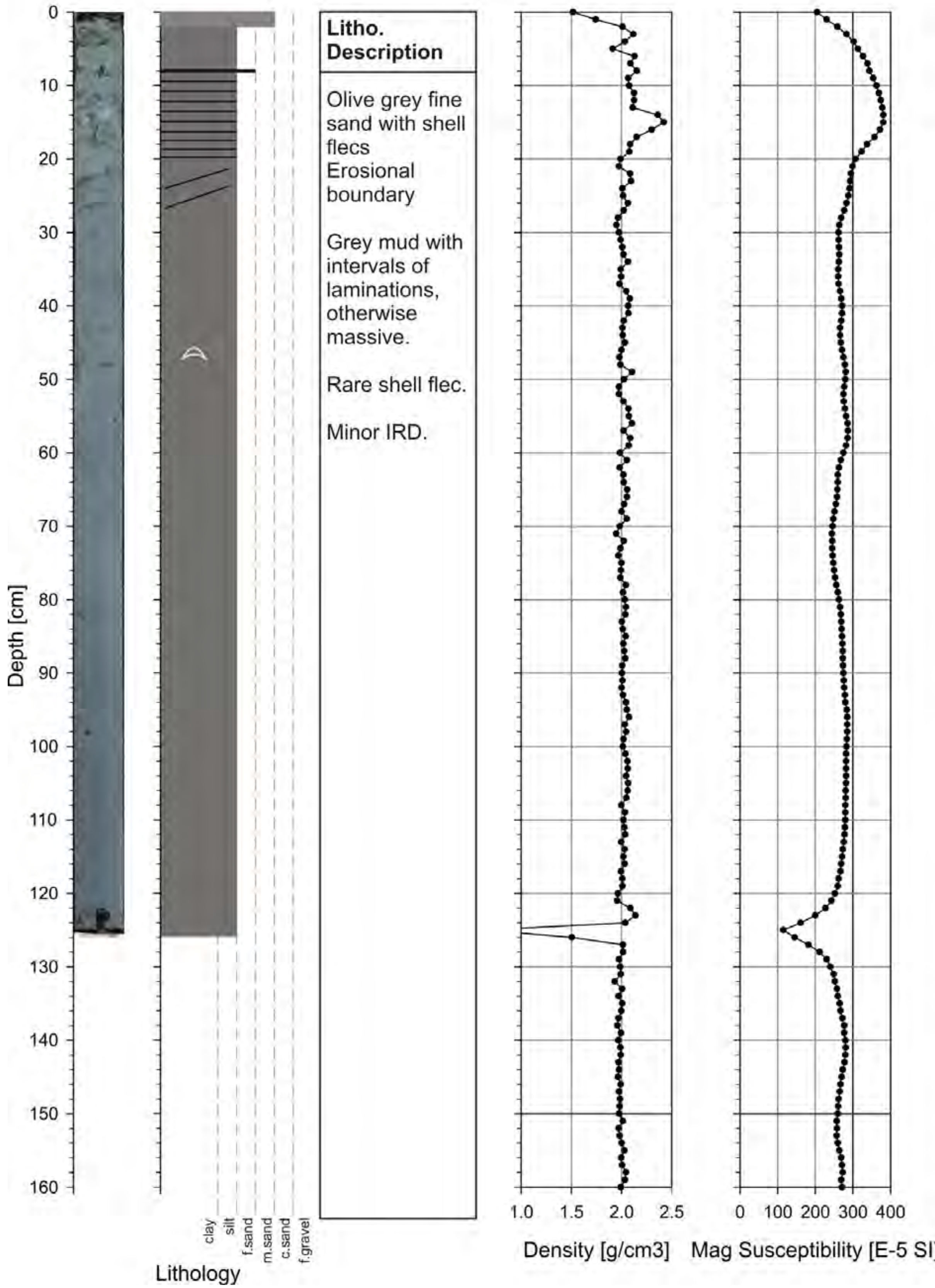


*Image did not have scale attached

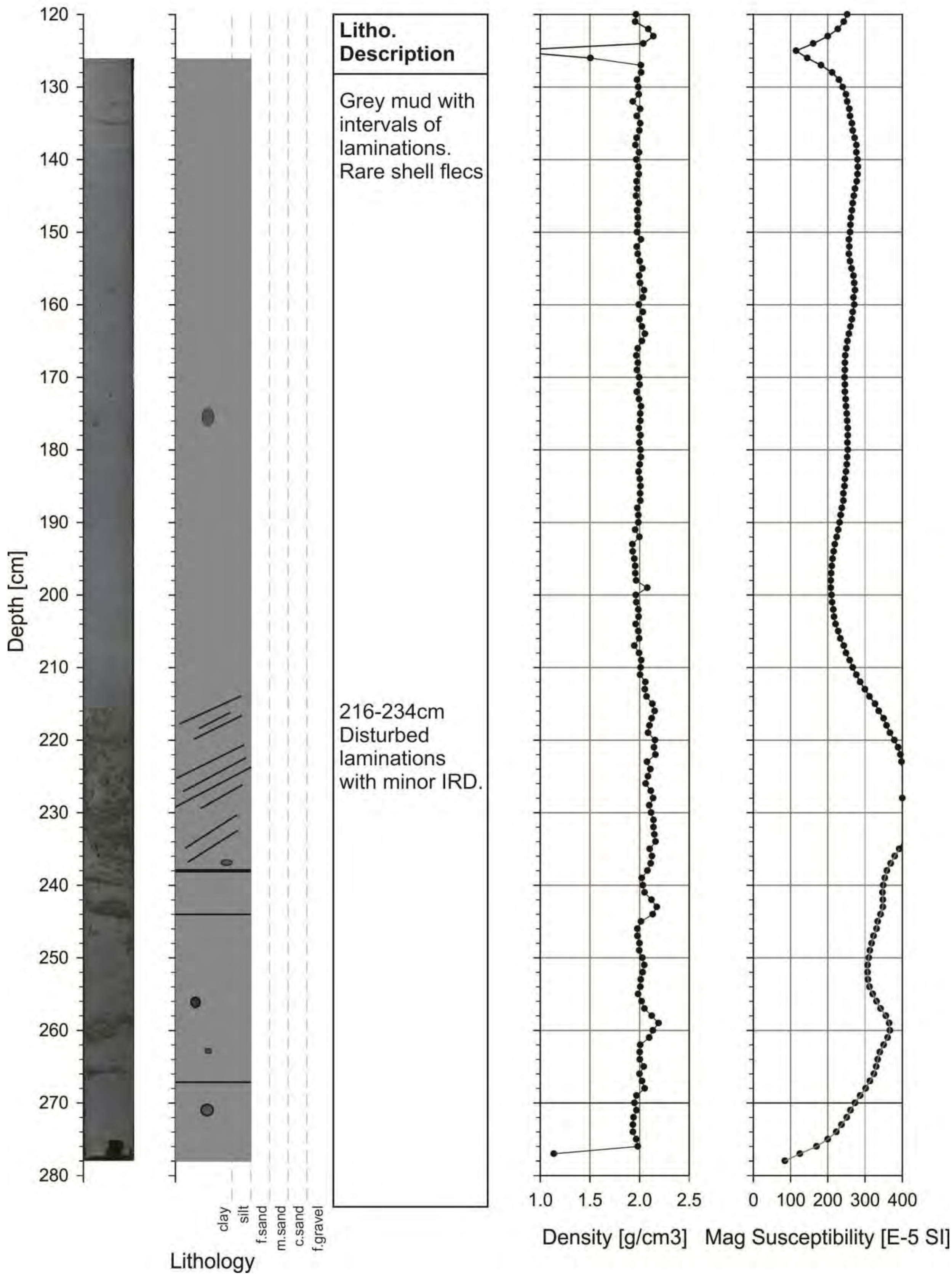
2015004PGC016 - Section 02



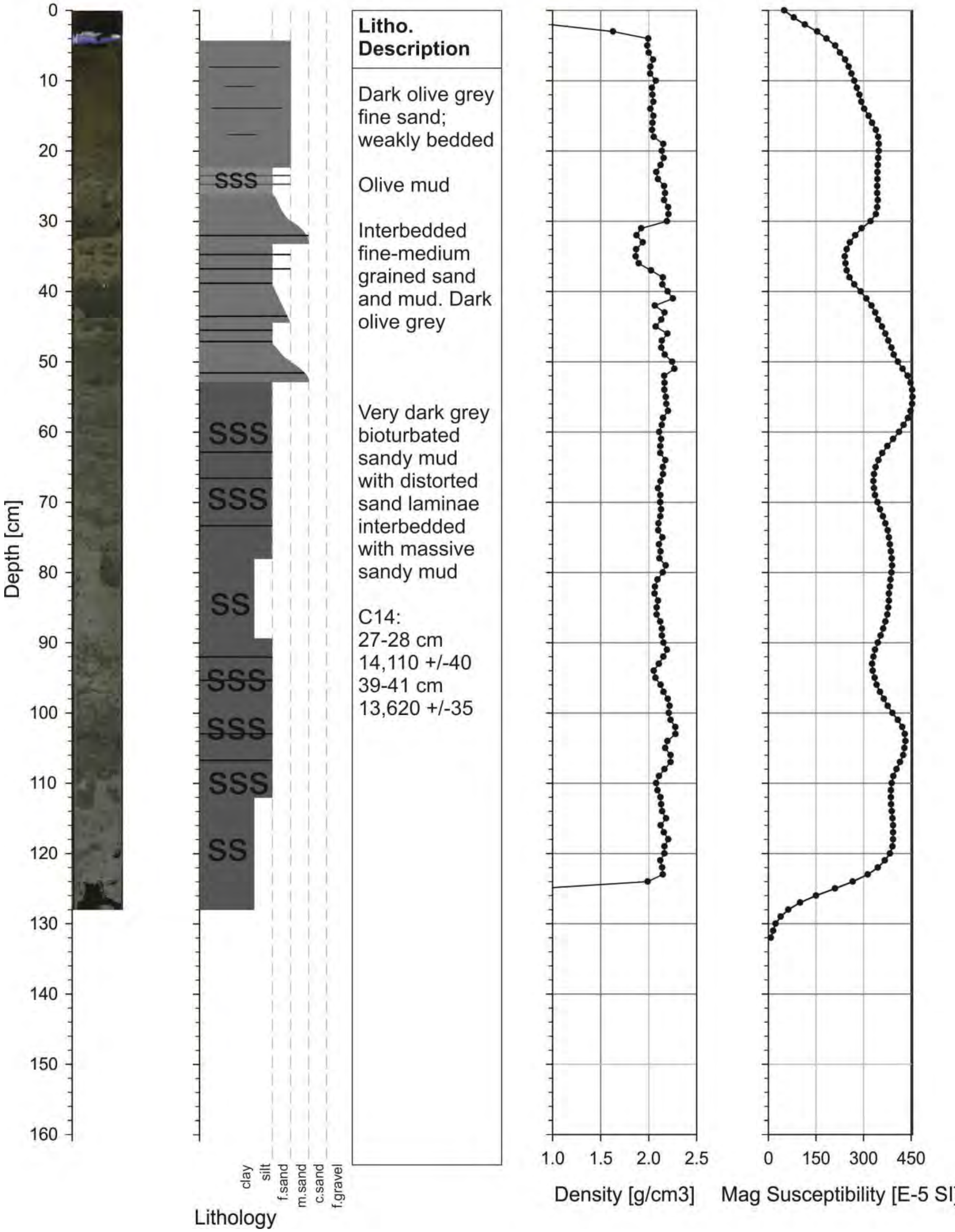
2015004PGC017 - Section 01



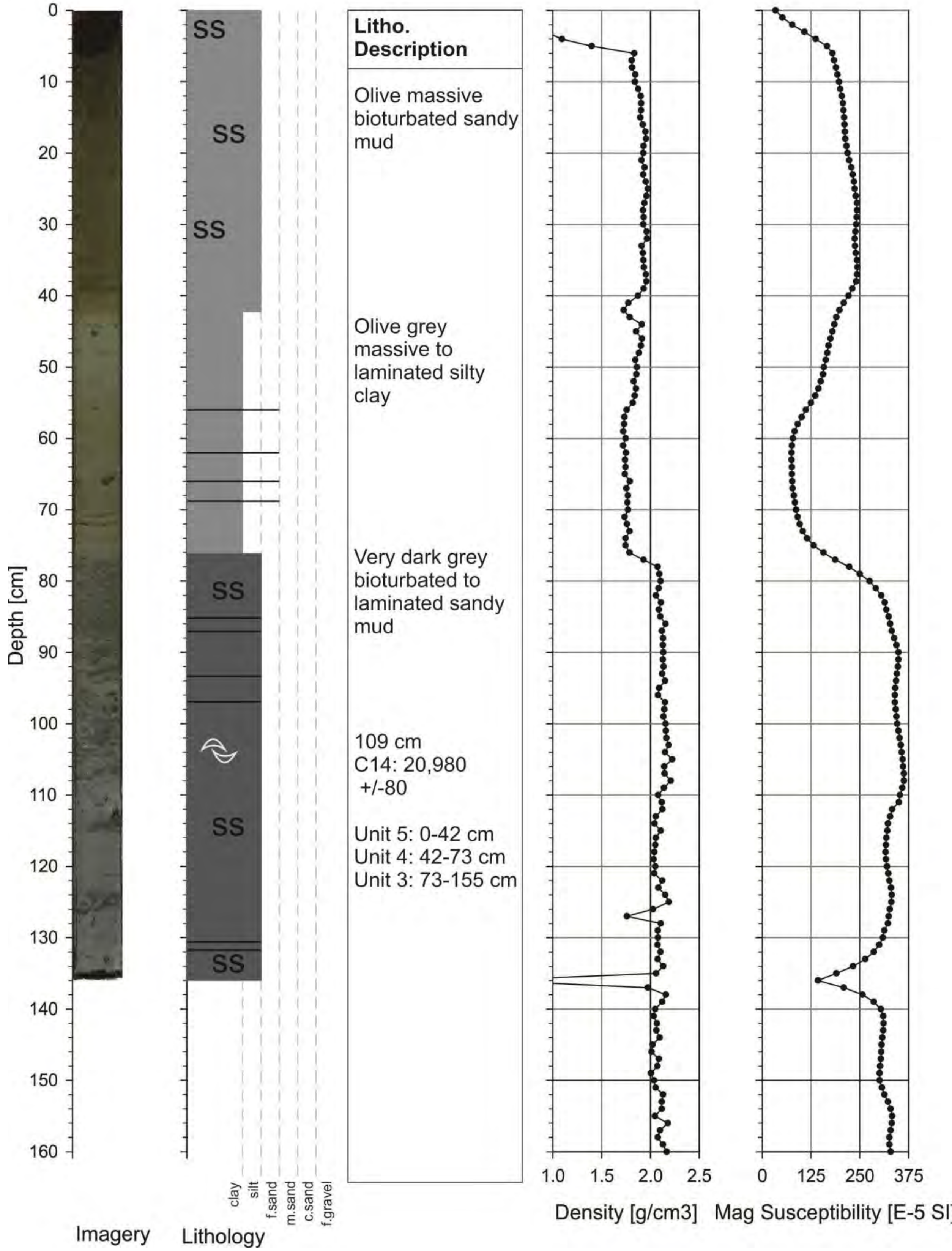
2015004PGC017 - Section 02



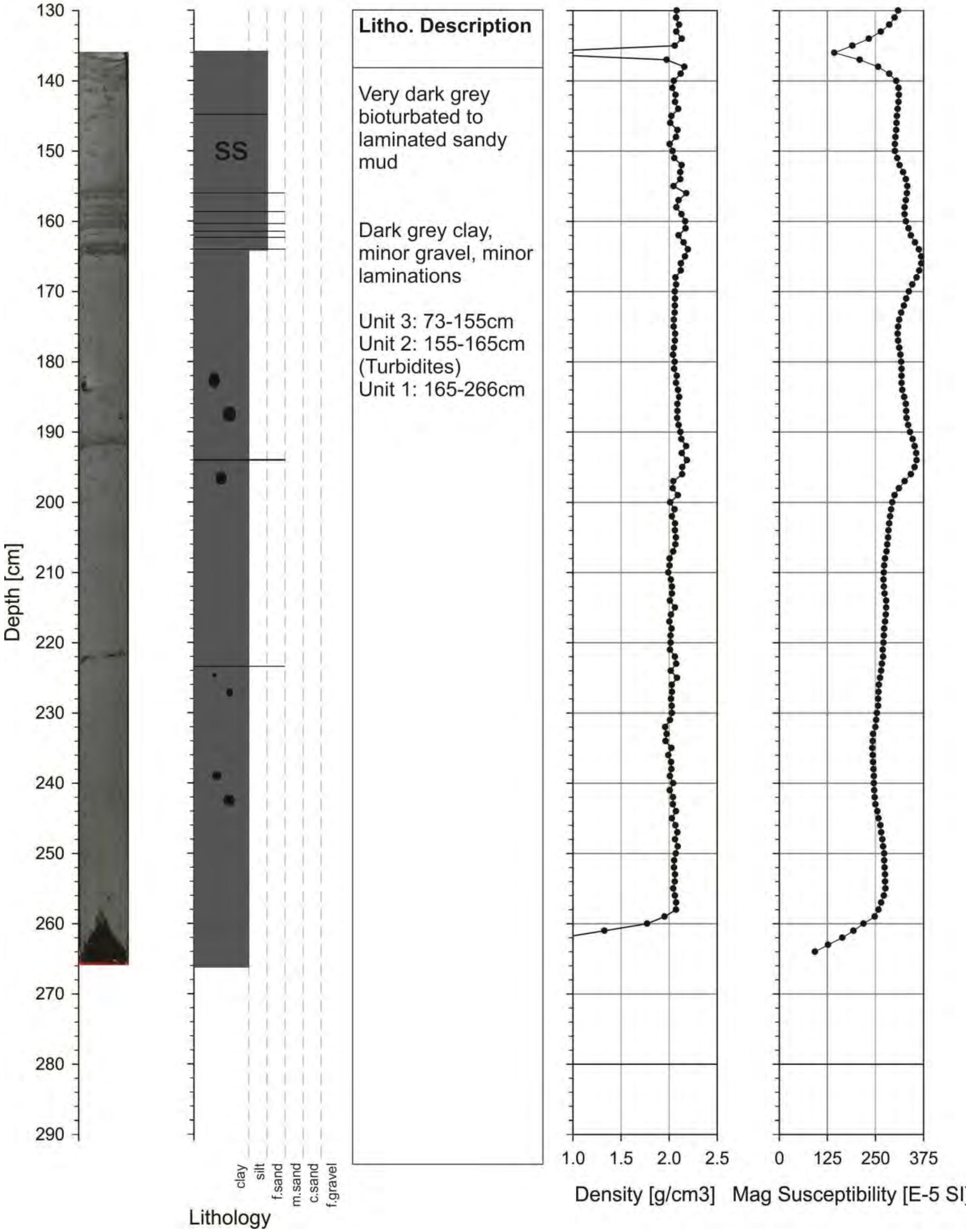
2015004PGC019



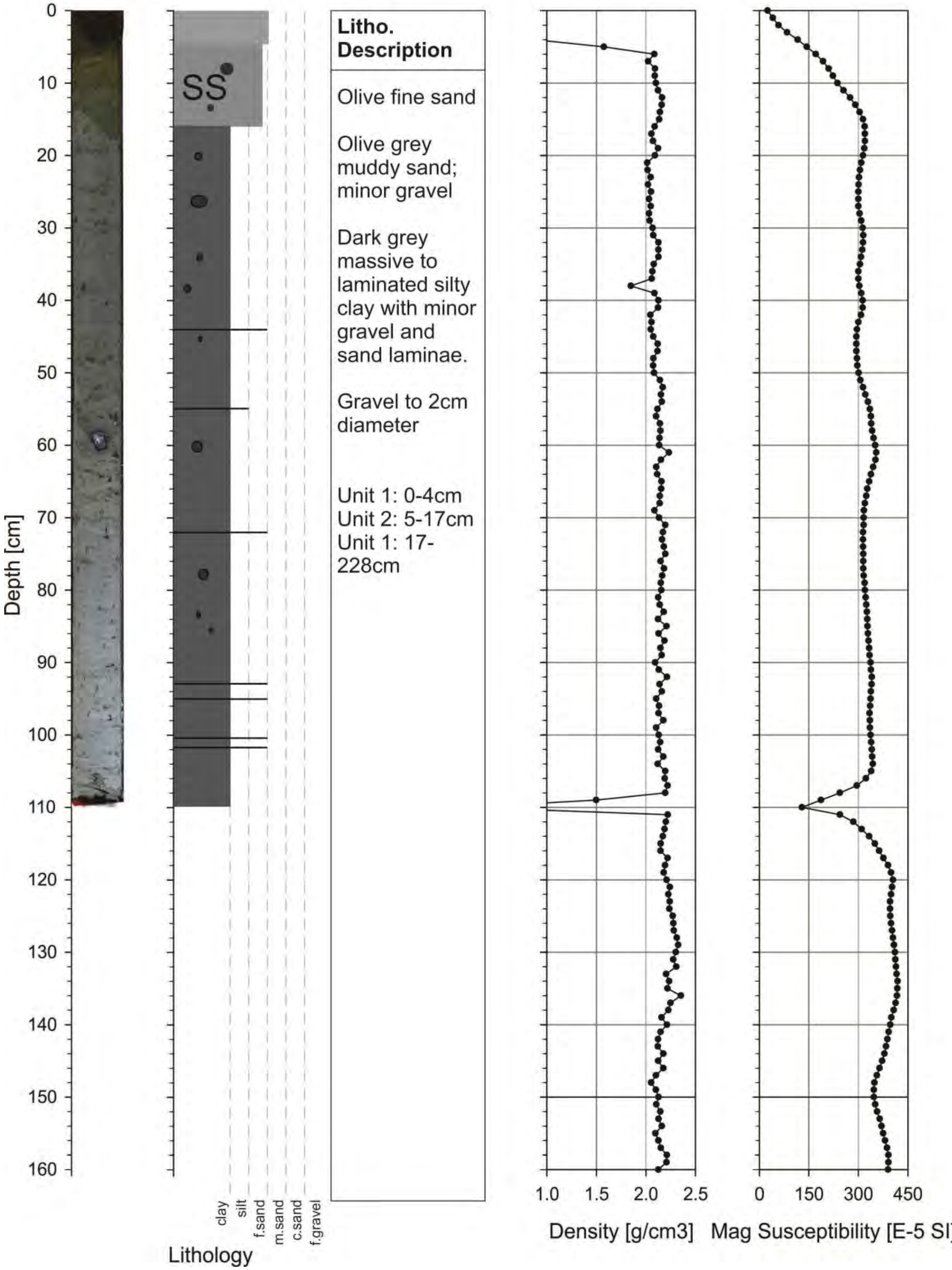
2015004PGC020 - Section 01



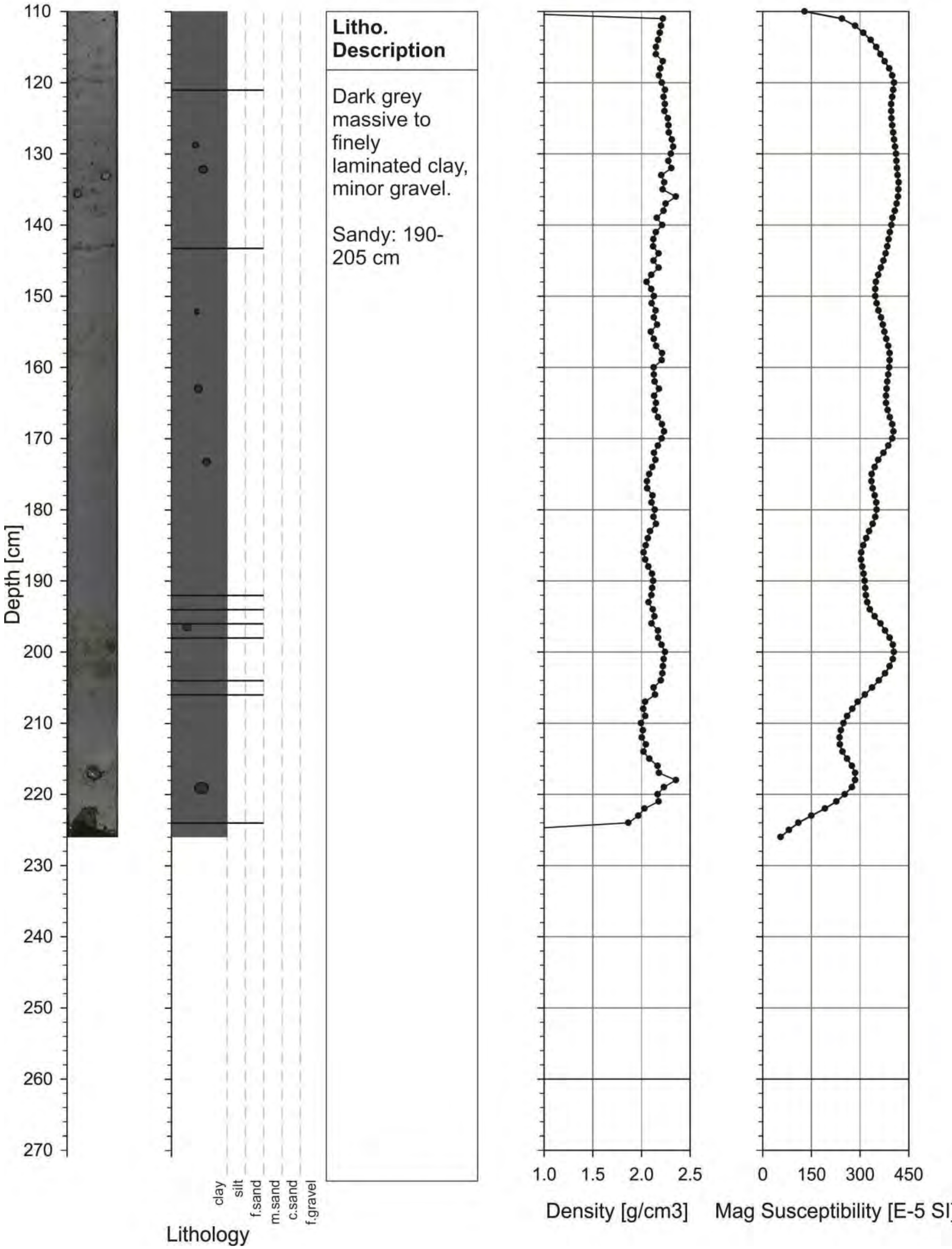
2015004PGC020 - Section 02

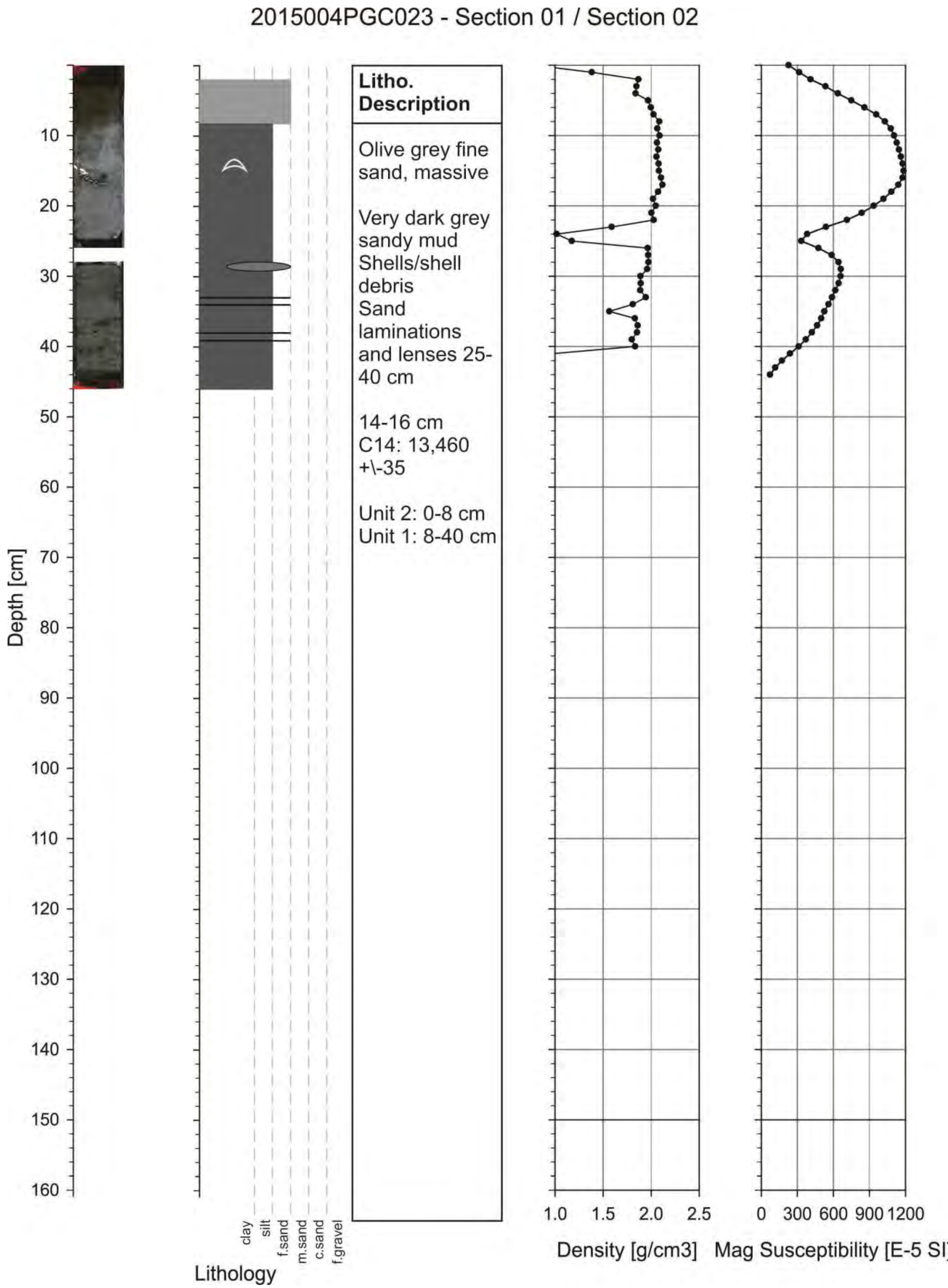


2015004PGC021 - Section 01

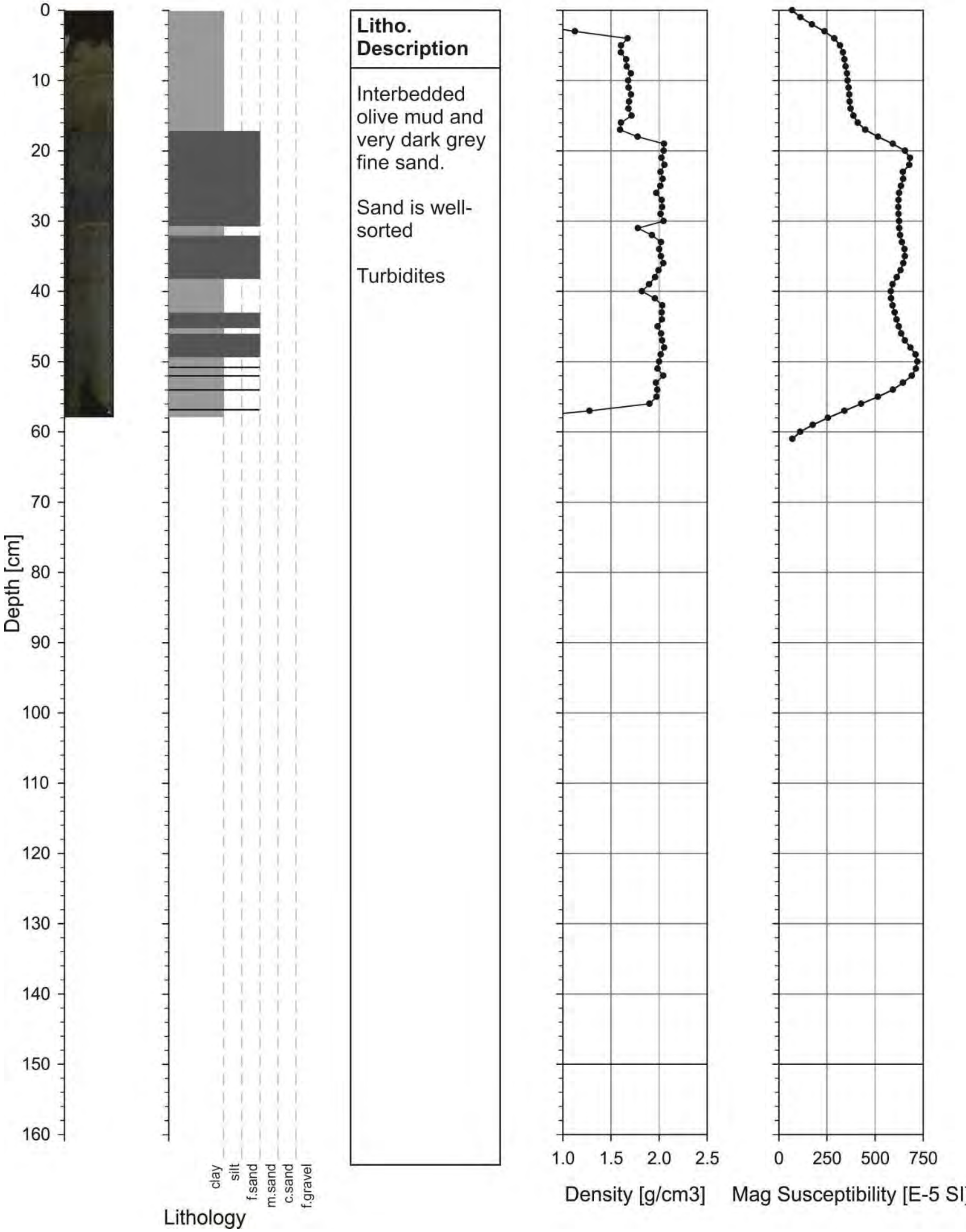


2015004PGC021 -Section 02

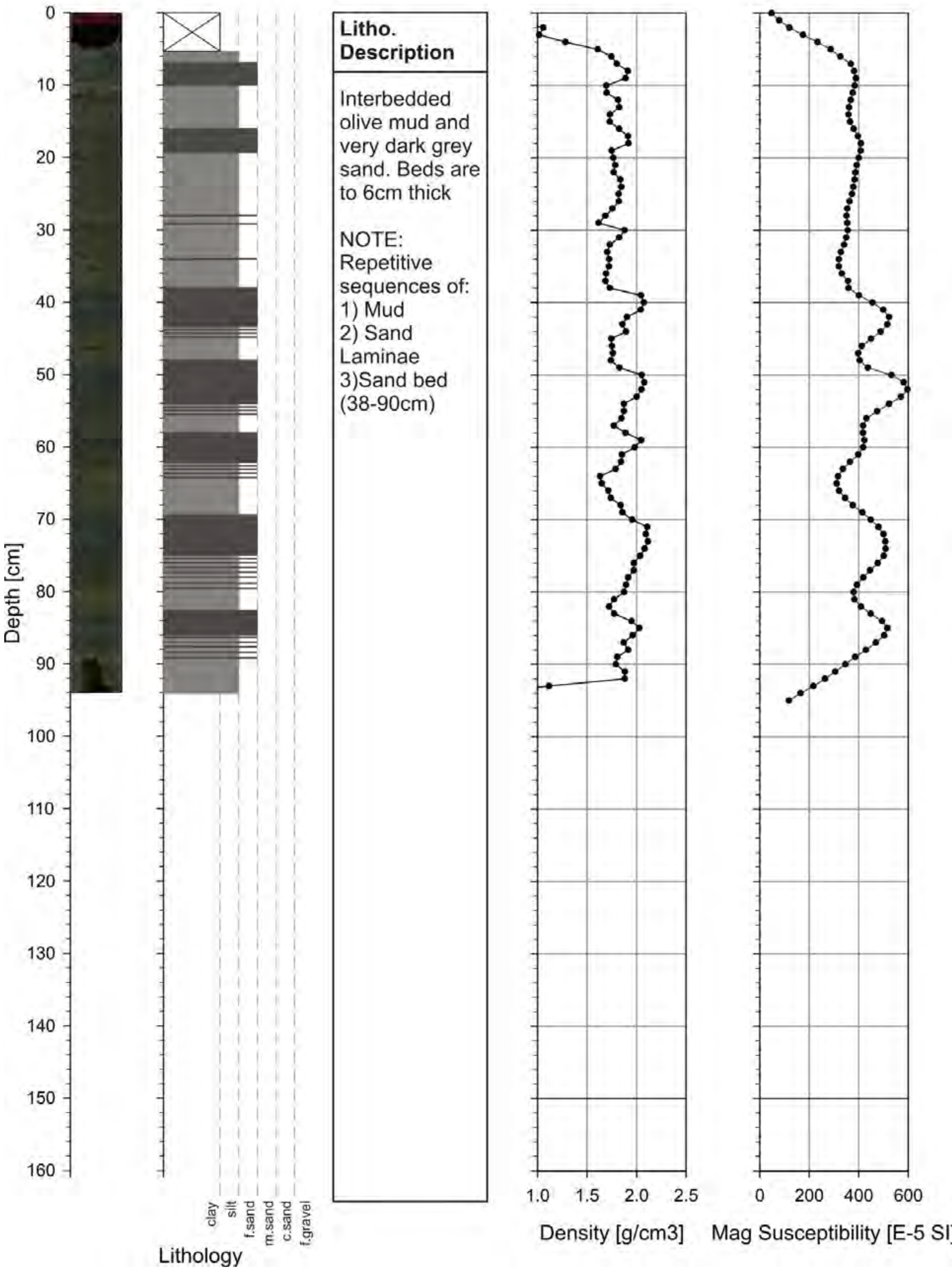



2015004PGC023 - Section 01 / Section 02
Depth [cm]
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
Litho. Description
Olive grey fine sand, massive
Very dark grey sandy mud
Shells/shell debris
Sand laminations and lenses 25-40 cm
14-16 cm C14: 13,460 +\-35
Unit 2: 0-8 cm
Unit 1: 8-40 cm
clay
silt
f.sand
m.sand
c.sand
f.gravel
Lithology
1.0
1.5
2.0
2.5
Density [g/cm3]
0
300
600
900
1200
Mag Susceptibility [E-5 SI]

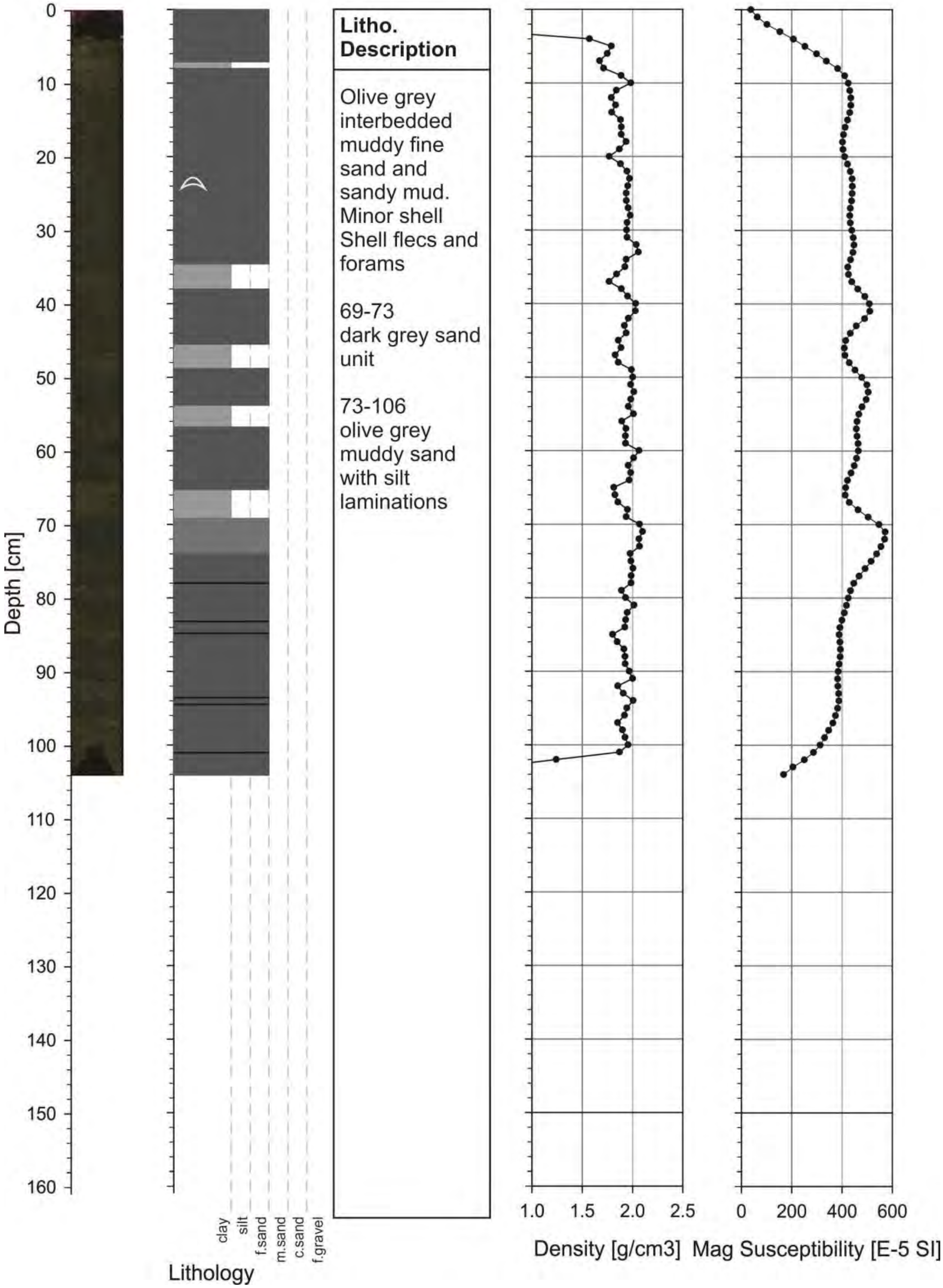
2015004PGC025



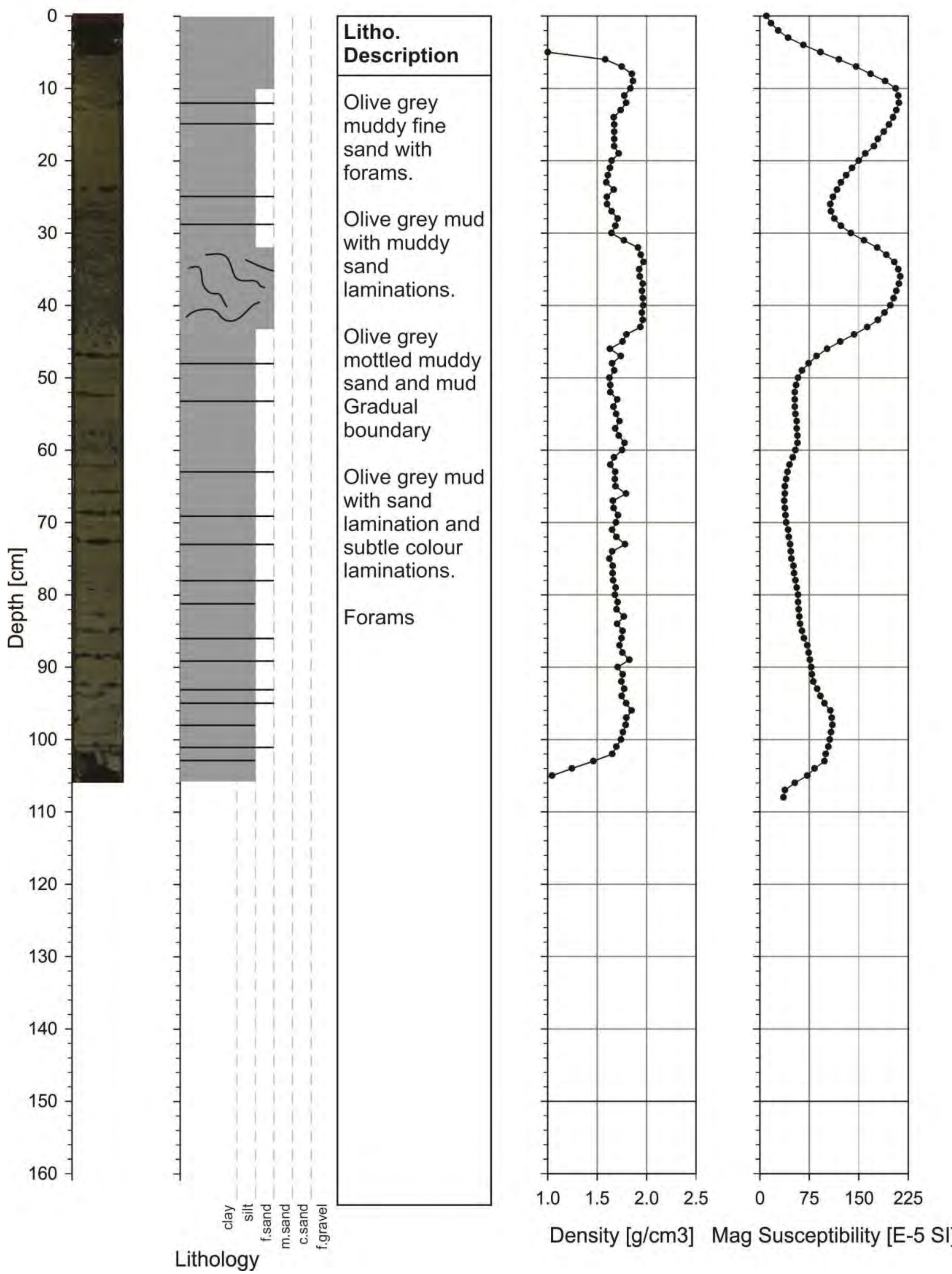
2015004PGC026



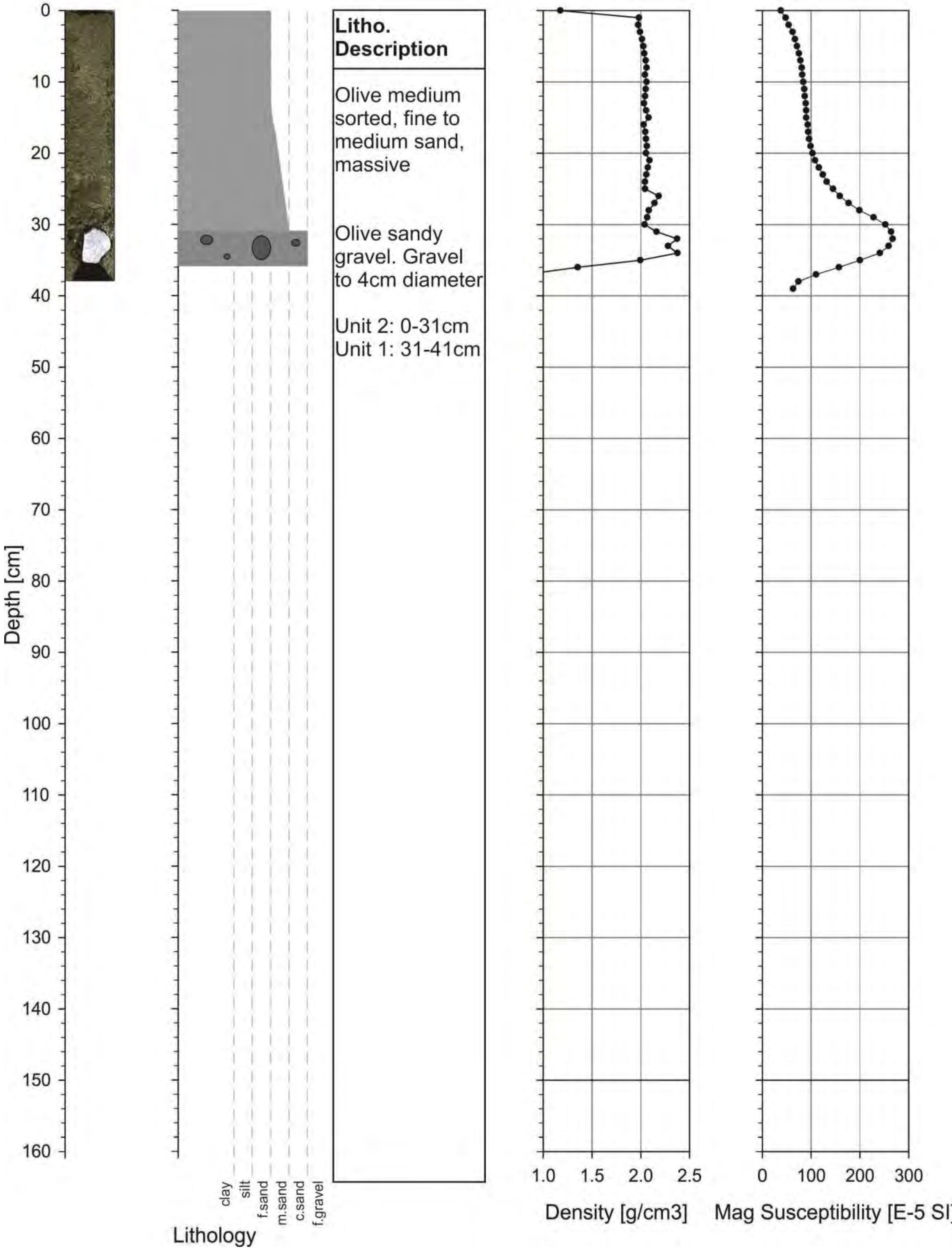
2015004PGC027



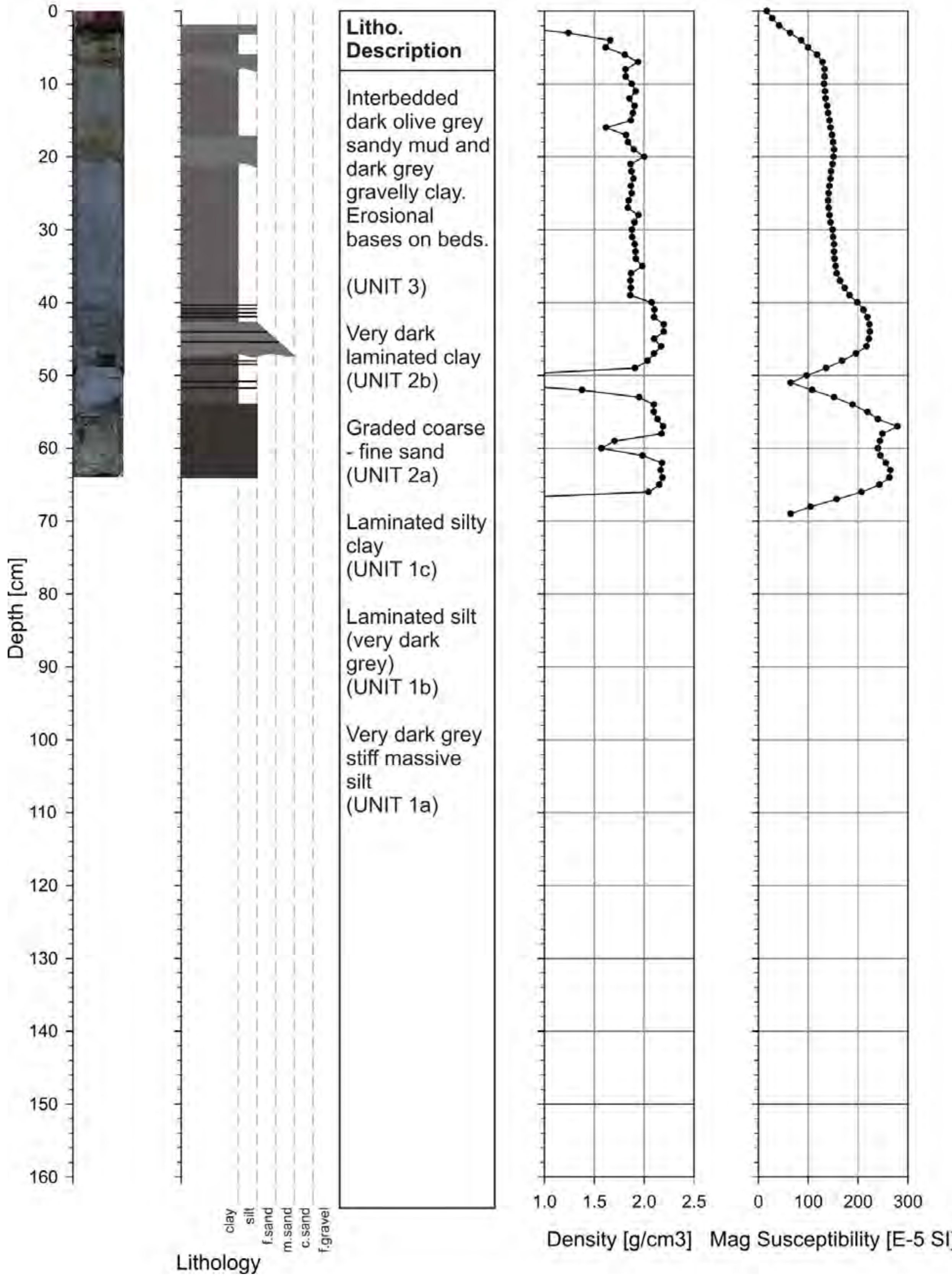
2015004PGC028



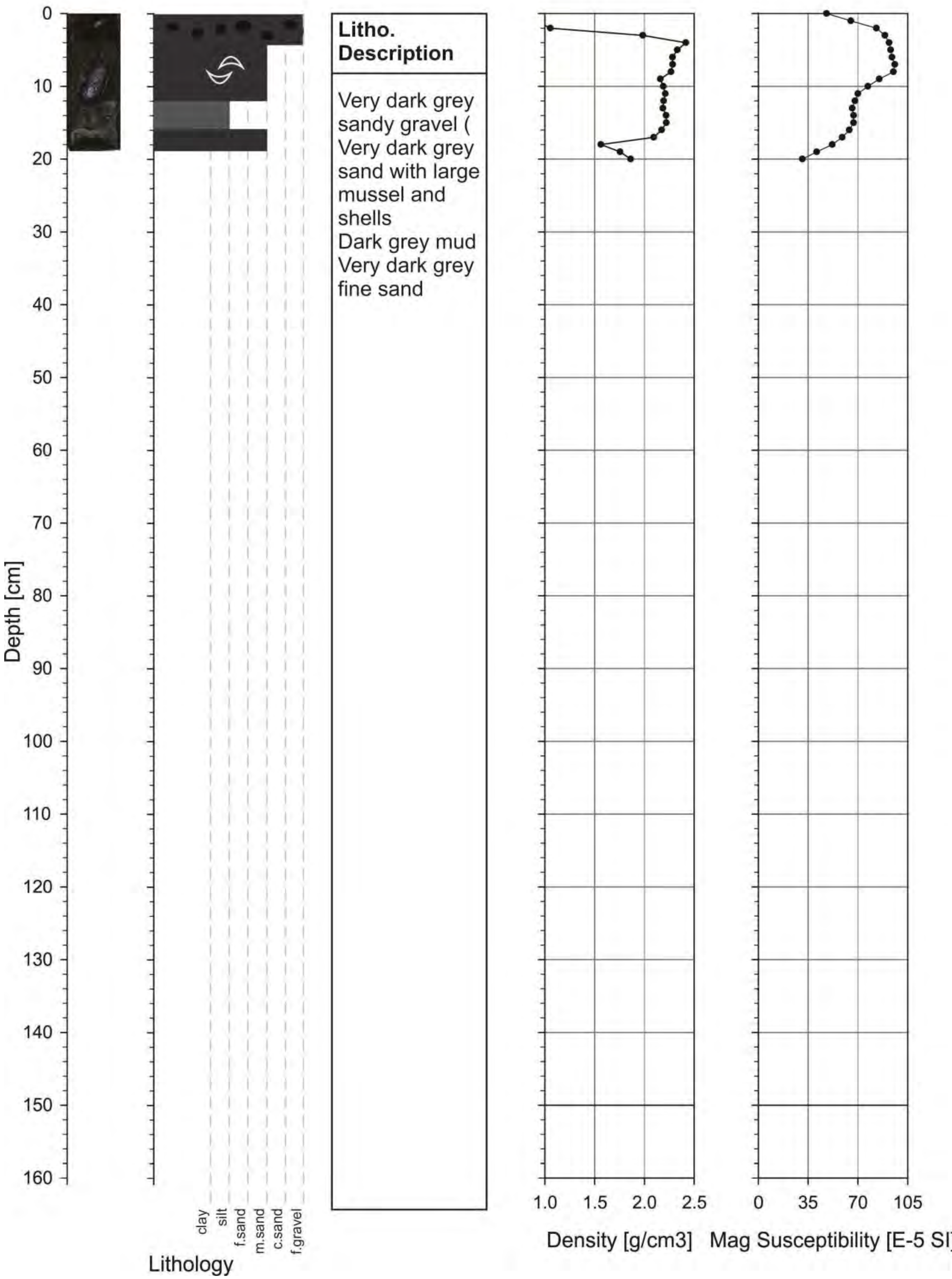
2015004PGC029



2015004PGC030 - Section 01/02



2015004PGC032AA



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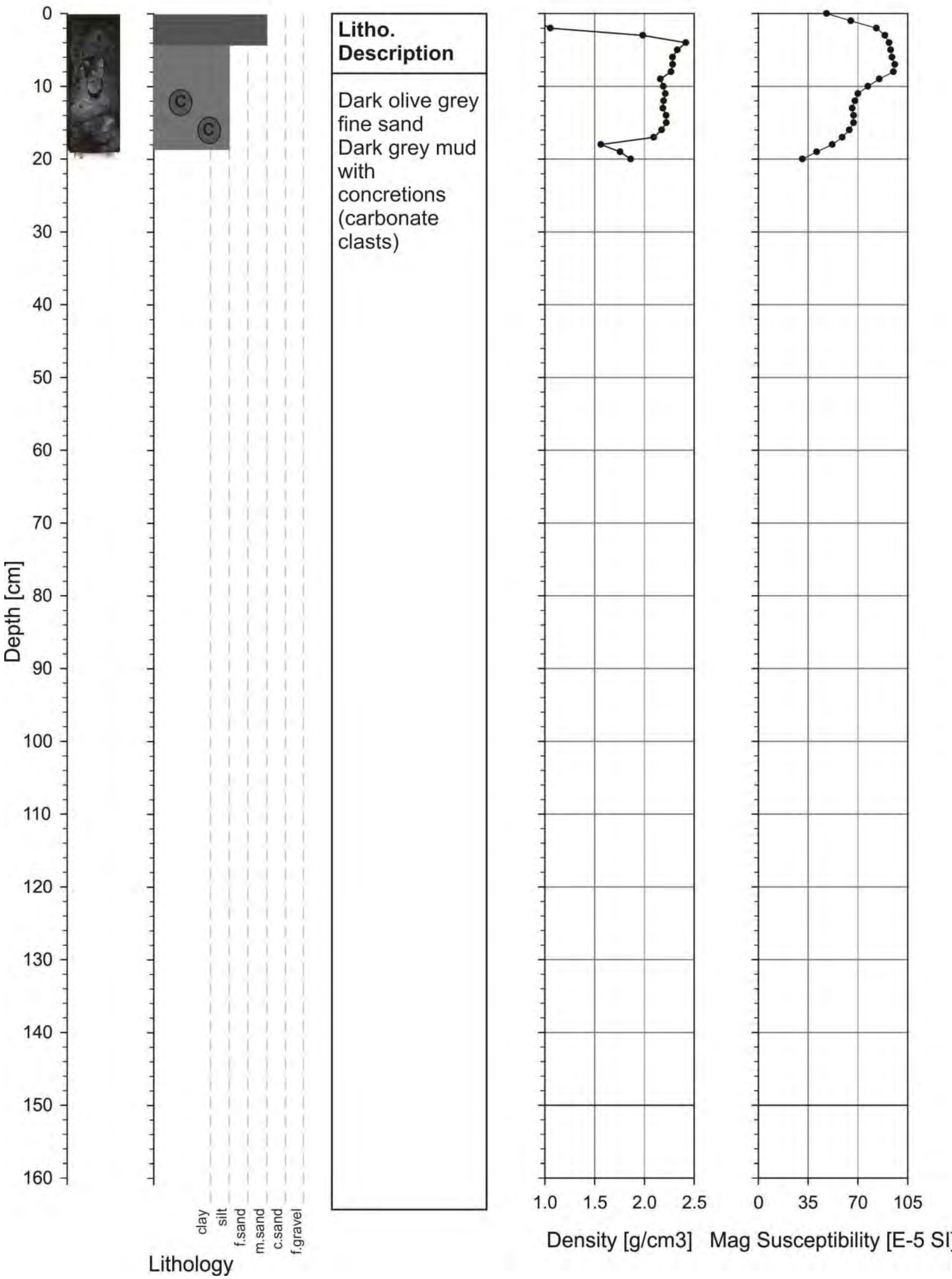
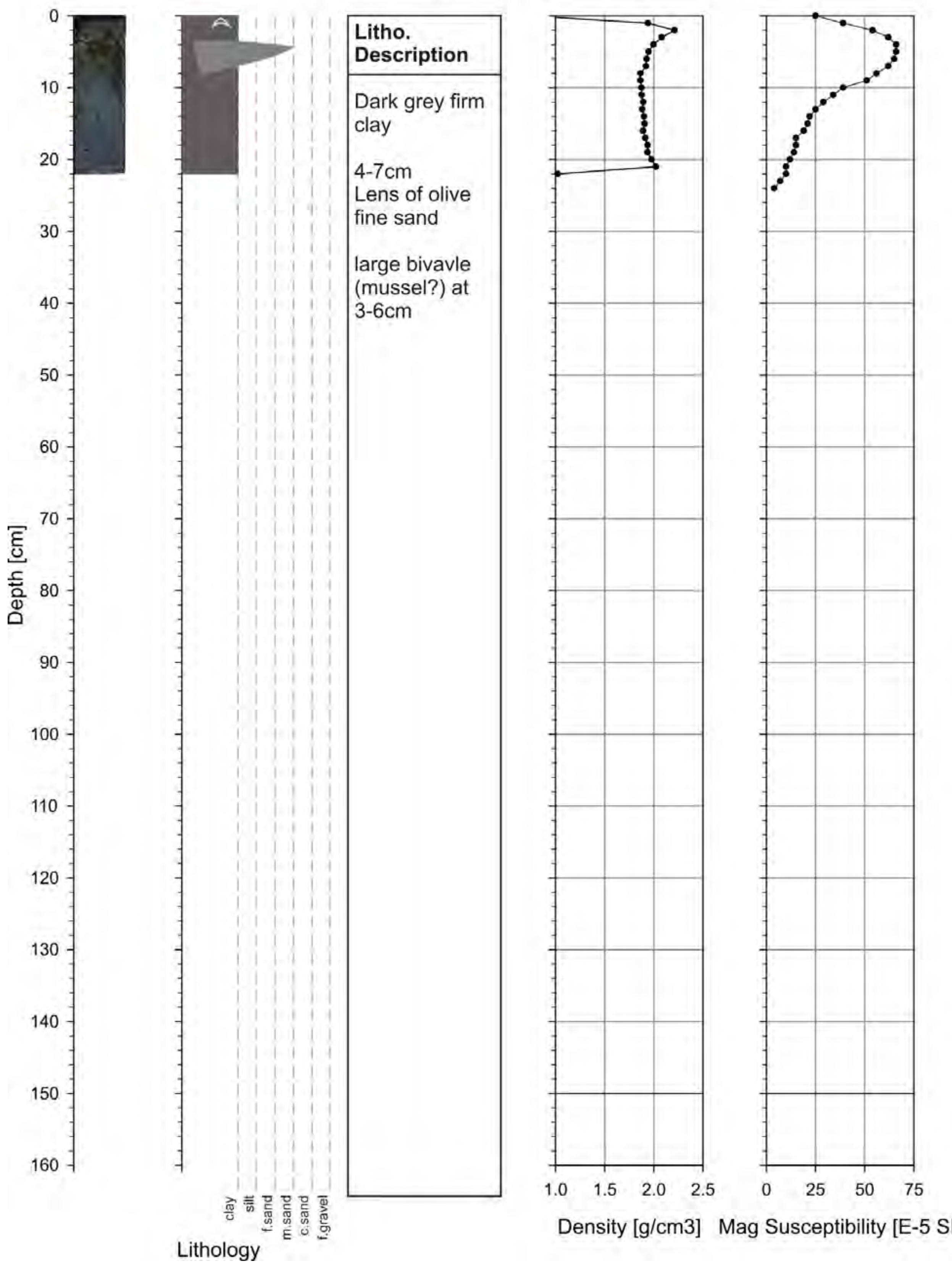
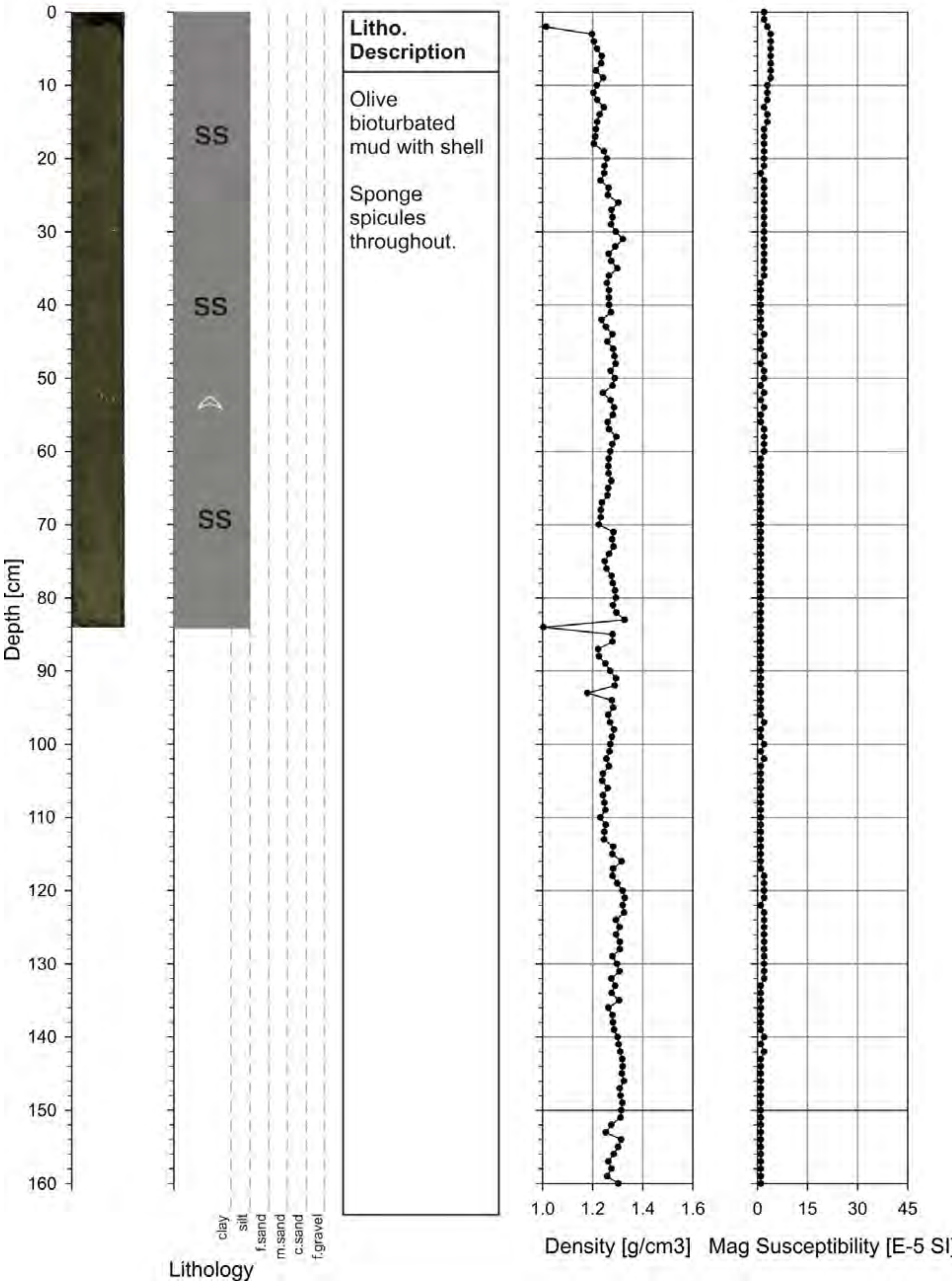


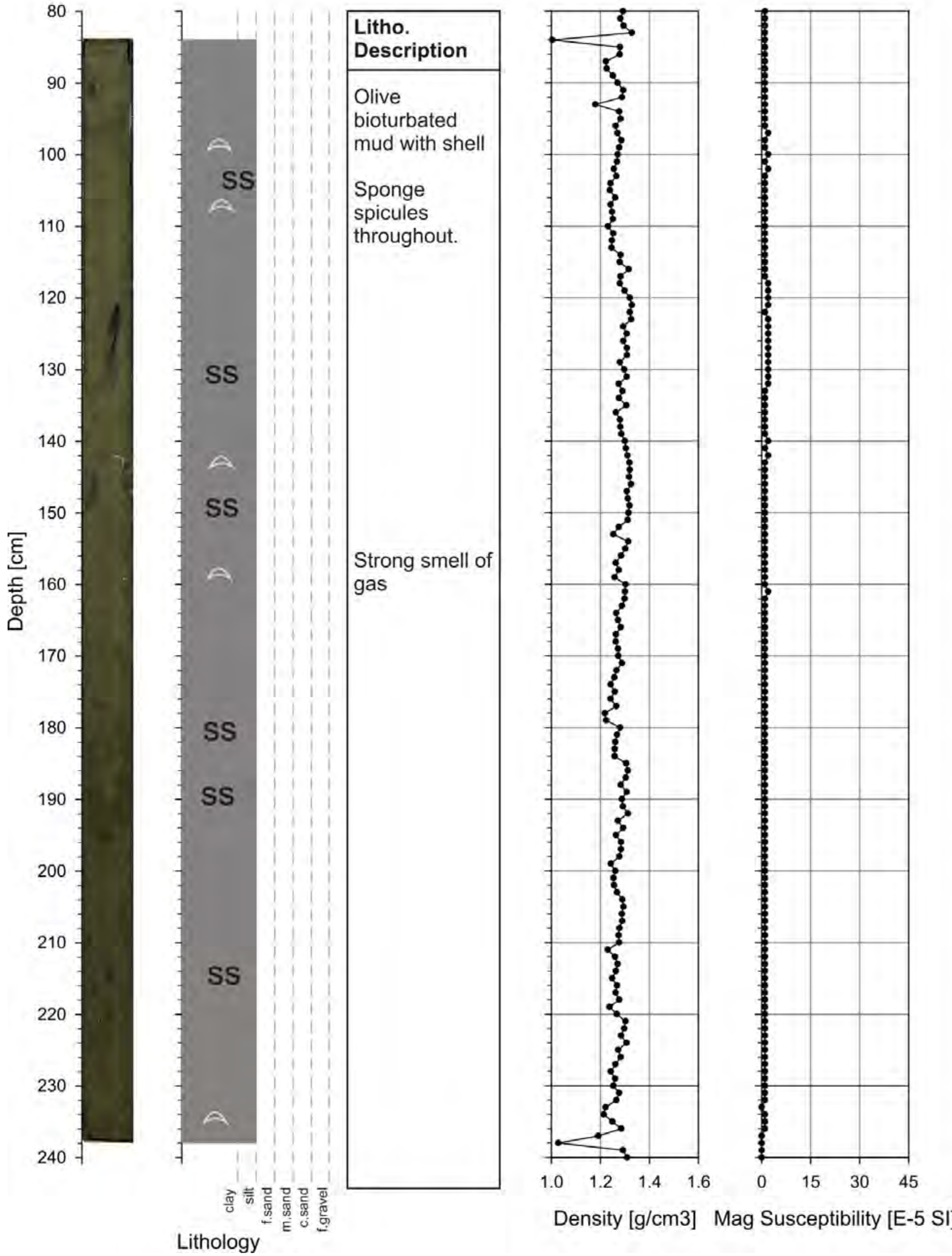
2015004PGC033



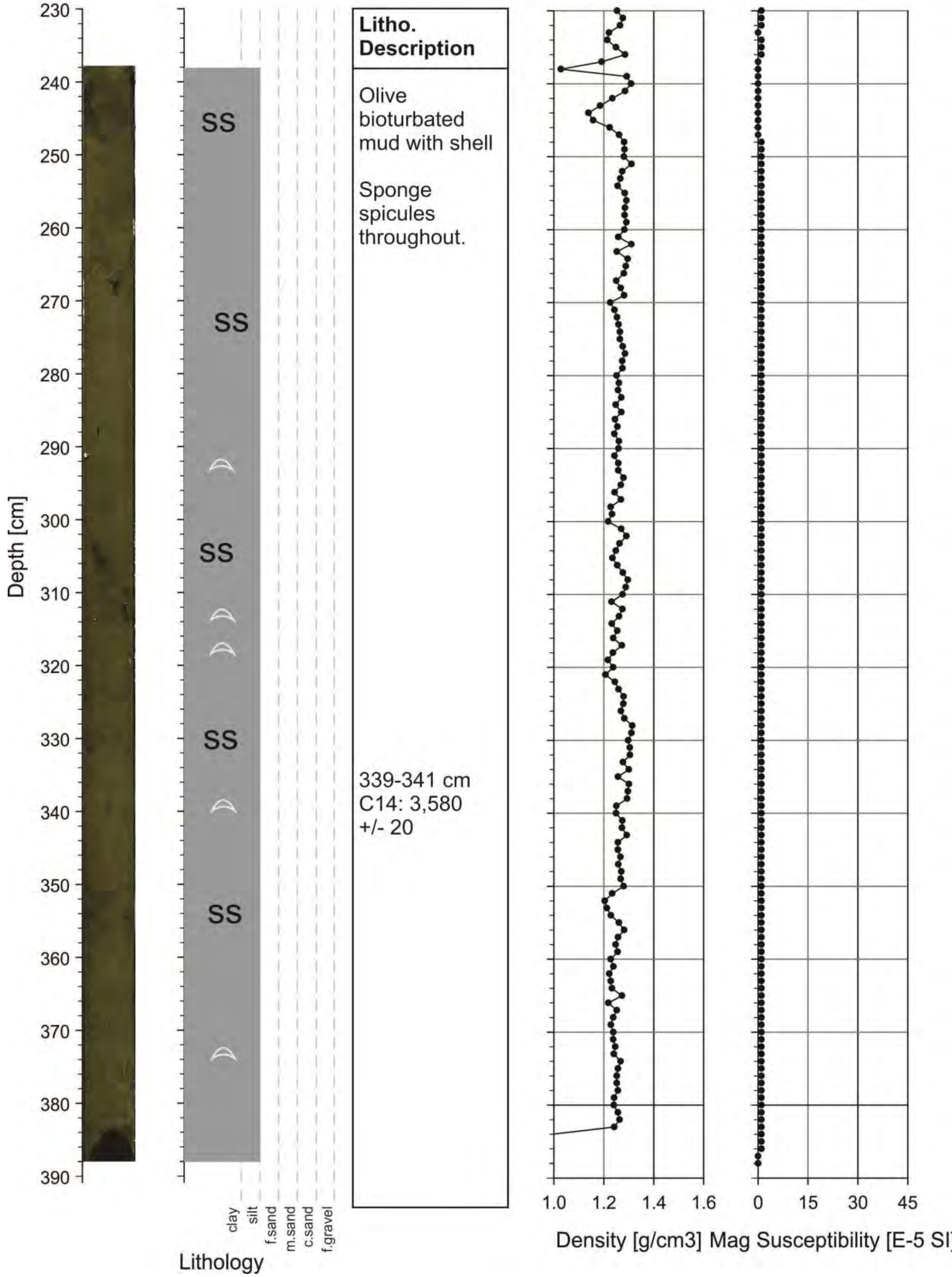
2015004PGC038 - Section 01



2015004PGC038 - Section 02



2015004PGC038 - Section 03



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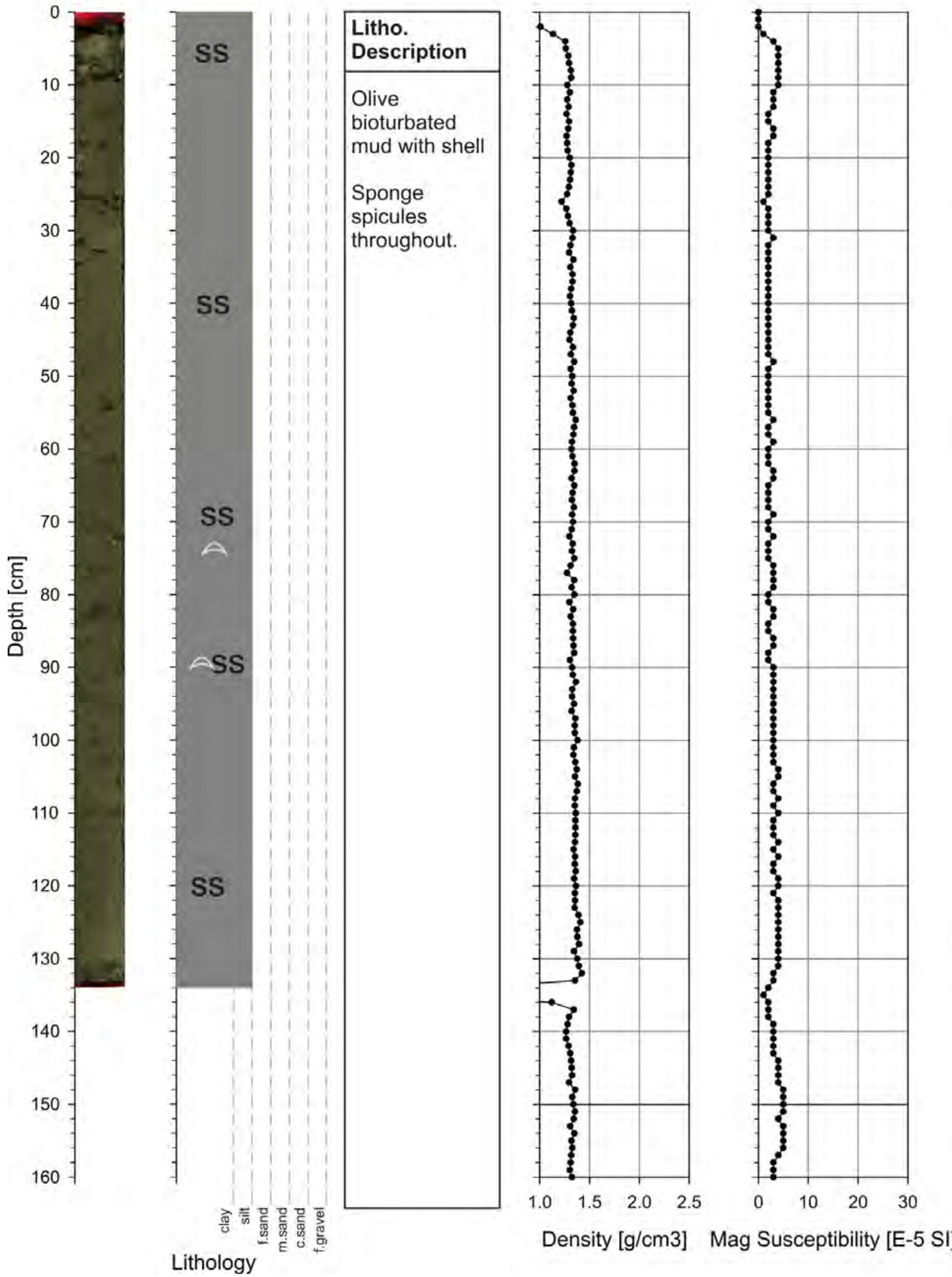

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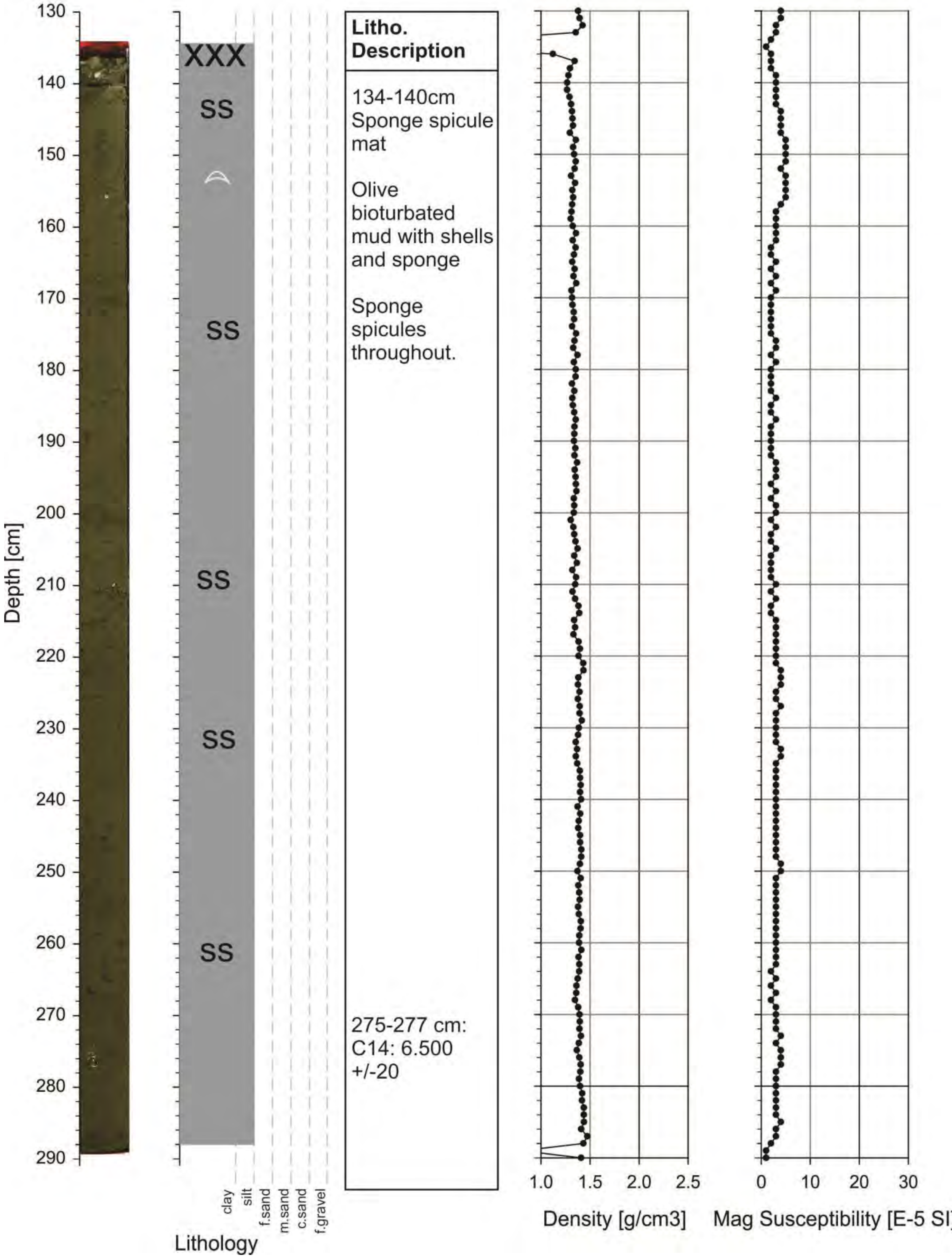
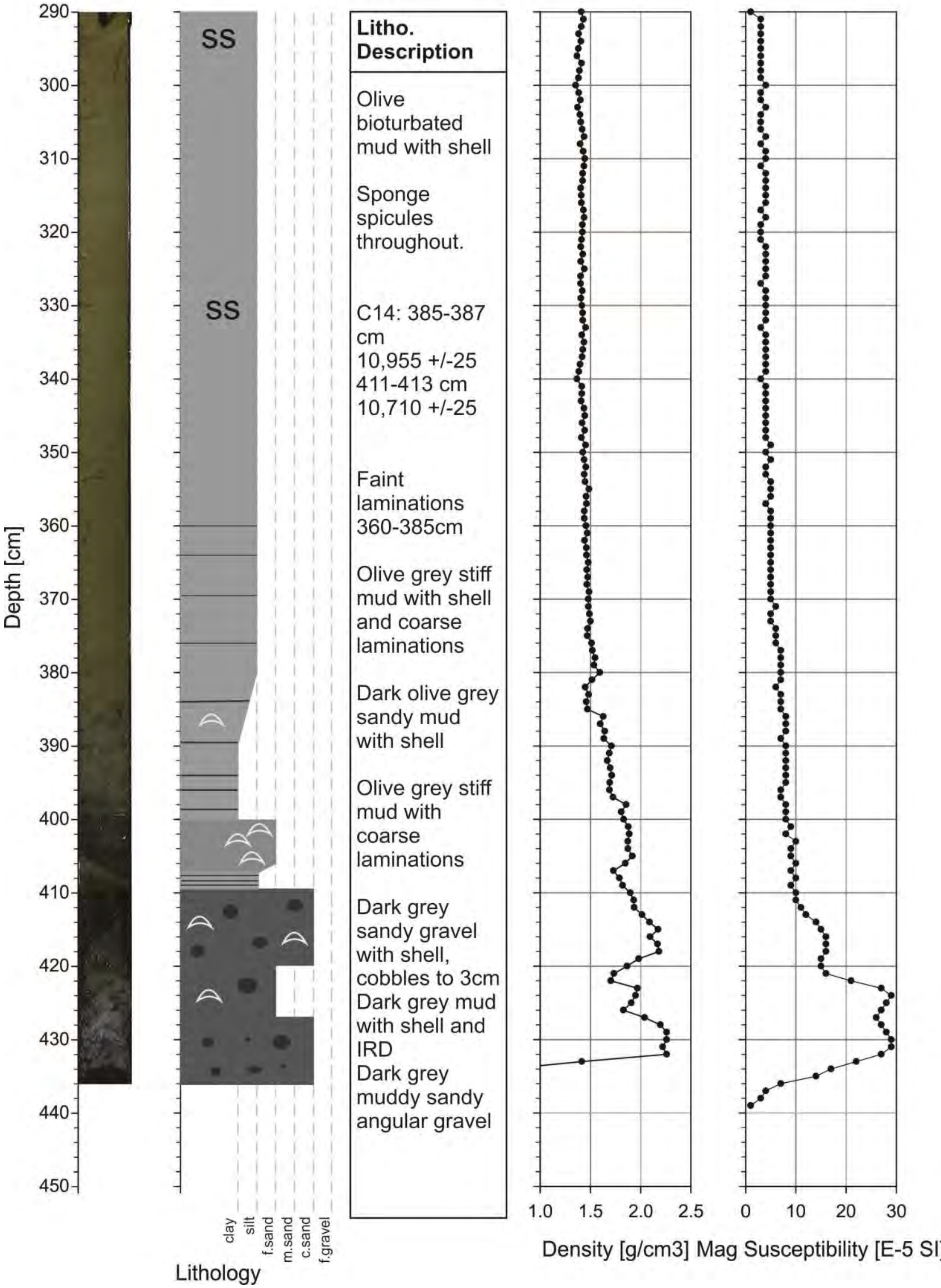
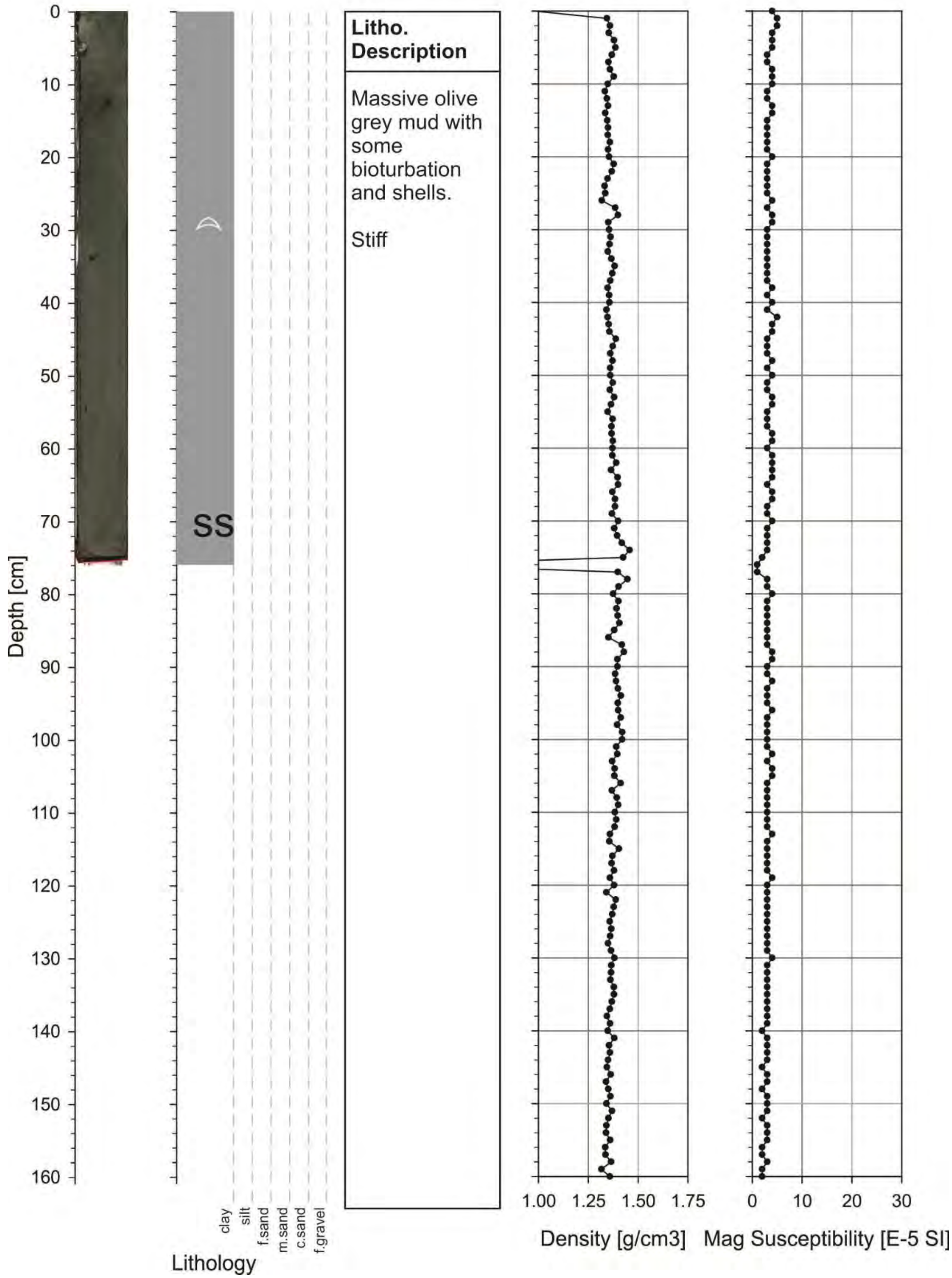


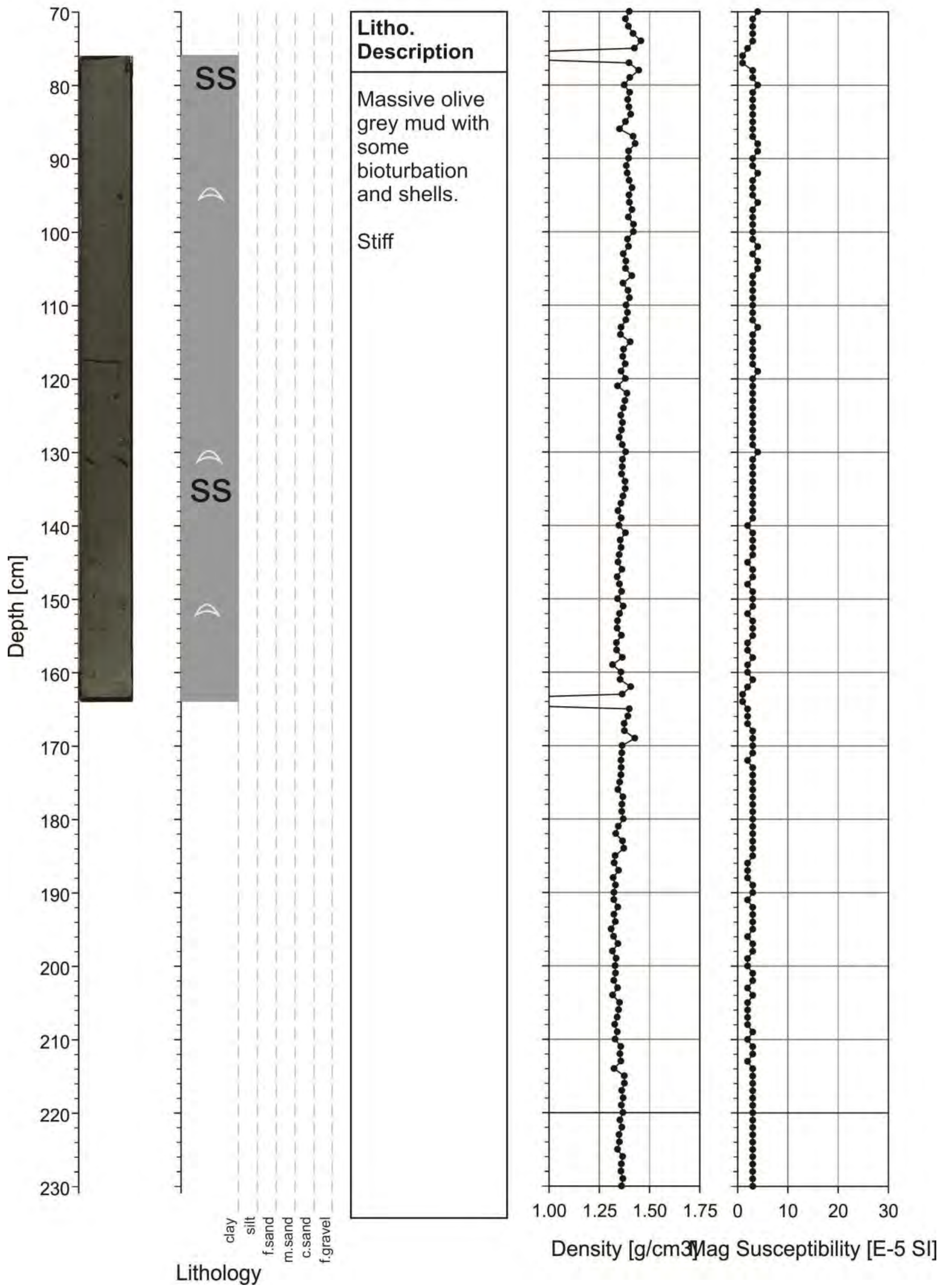
2015004PGC039 - Section 03



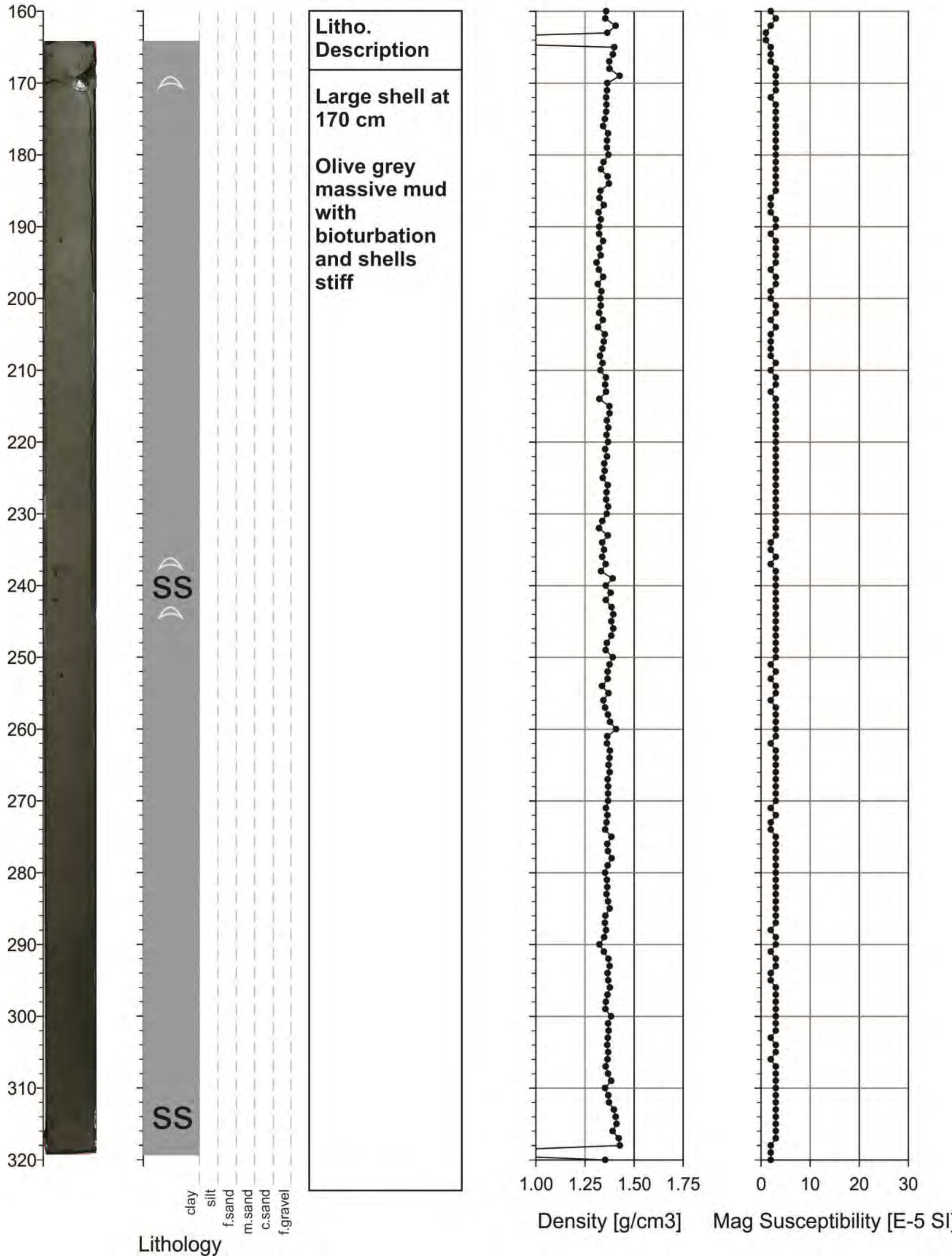
2015004PGC040 - Section 01



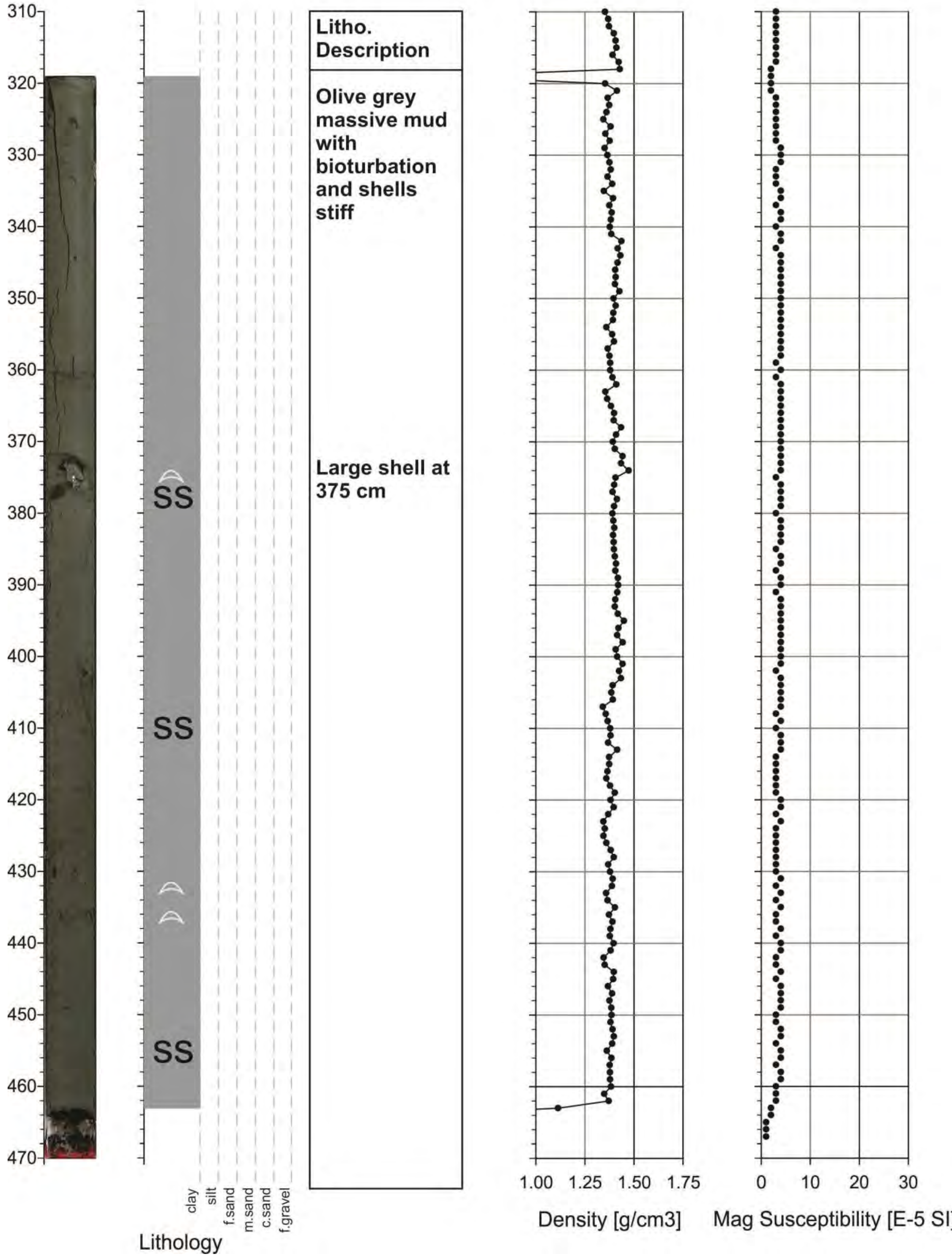
2015004PGC040 - Section 02



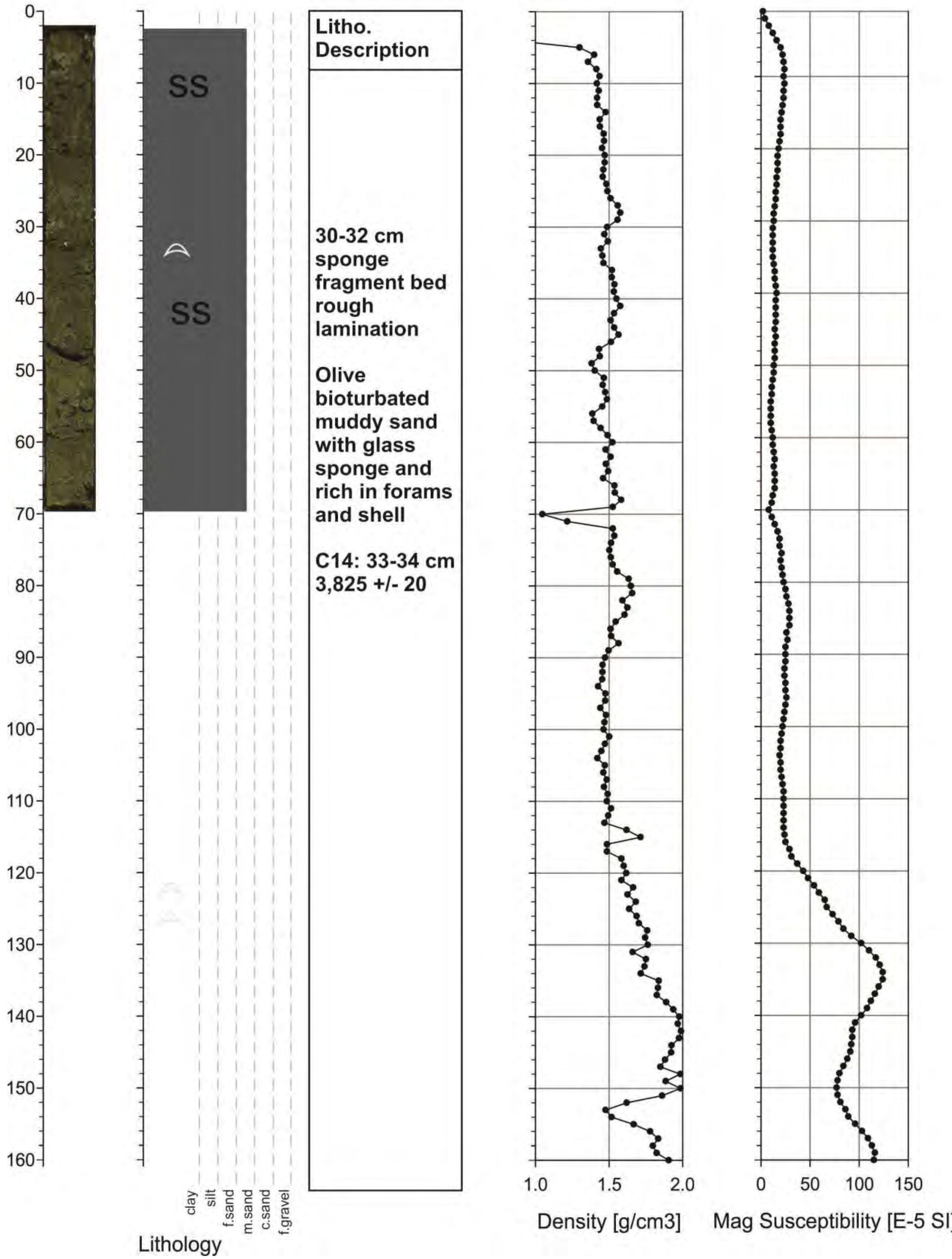
2015004PGC040 - Section 03



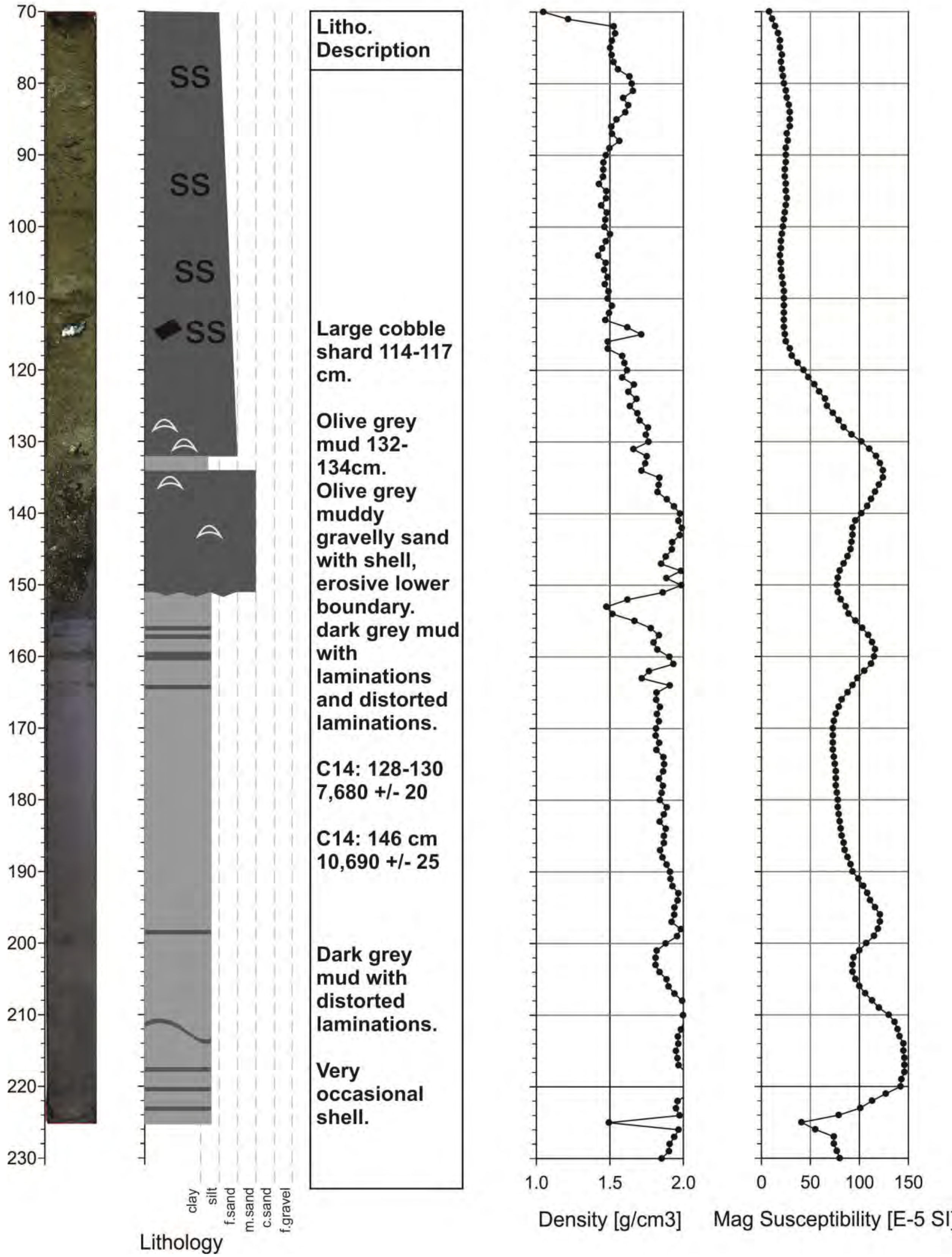
2015004PGC040 - Section 04



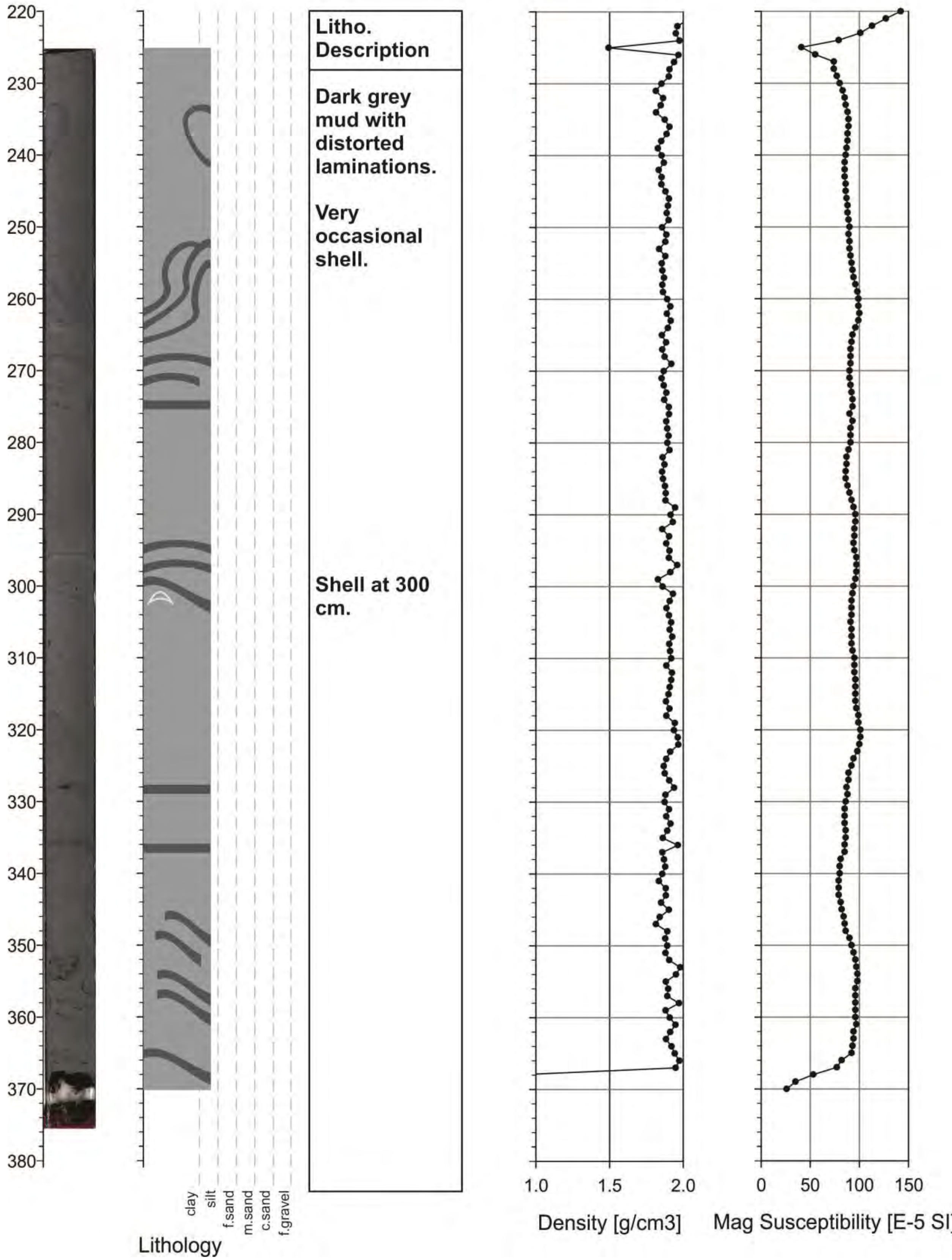
2015004PGC041 - Section 01



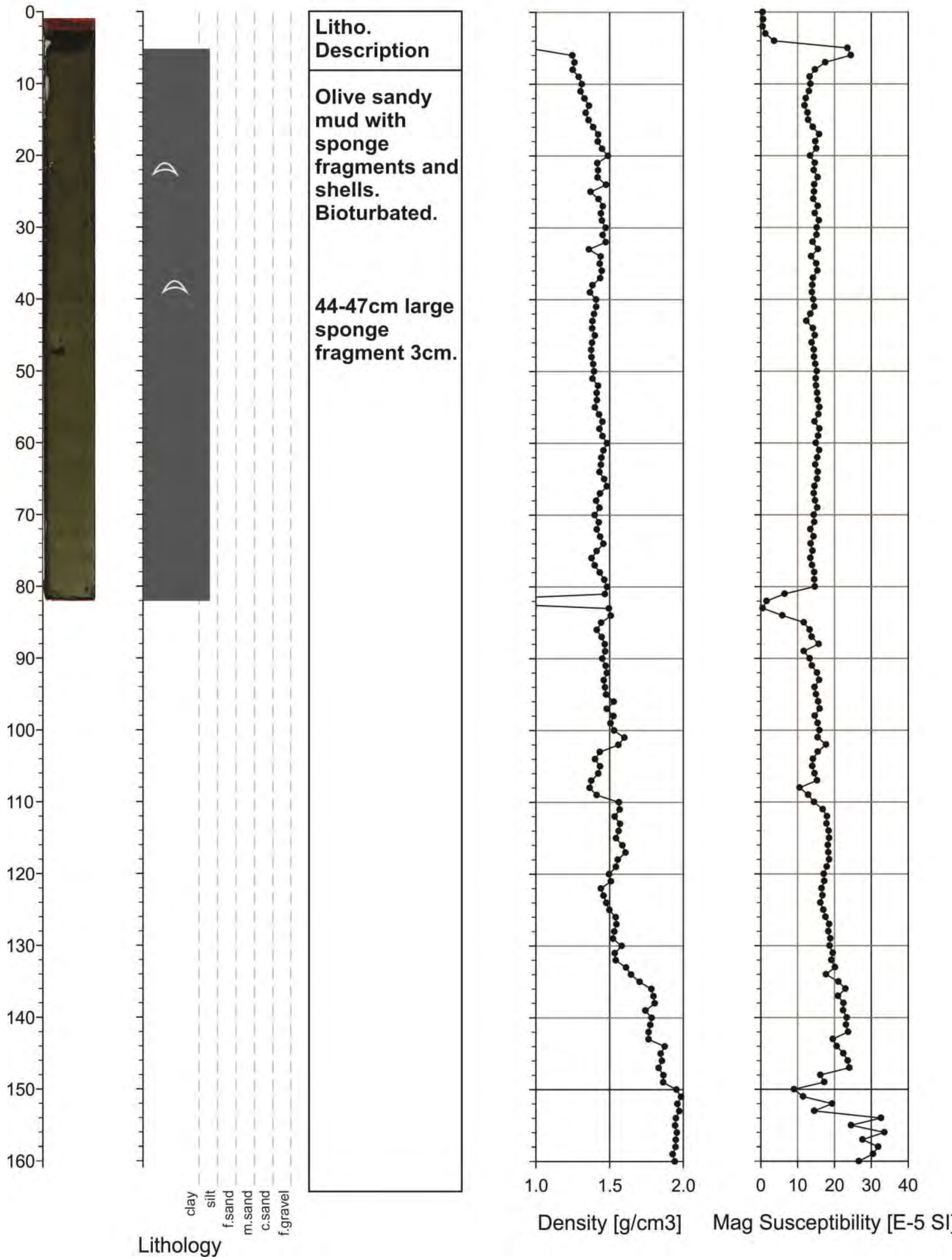
2015004PGC041 - Section 02



2015004PGC041 - Section 03

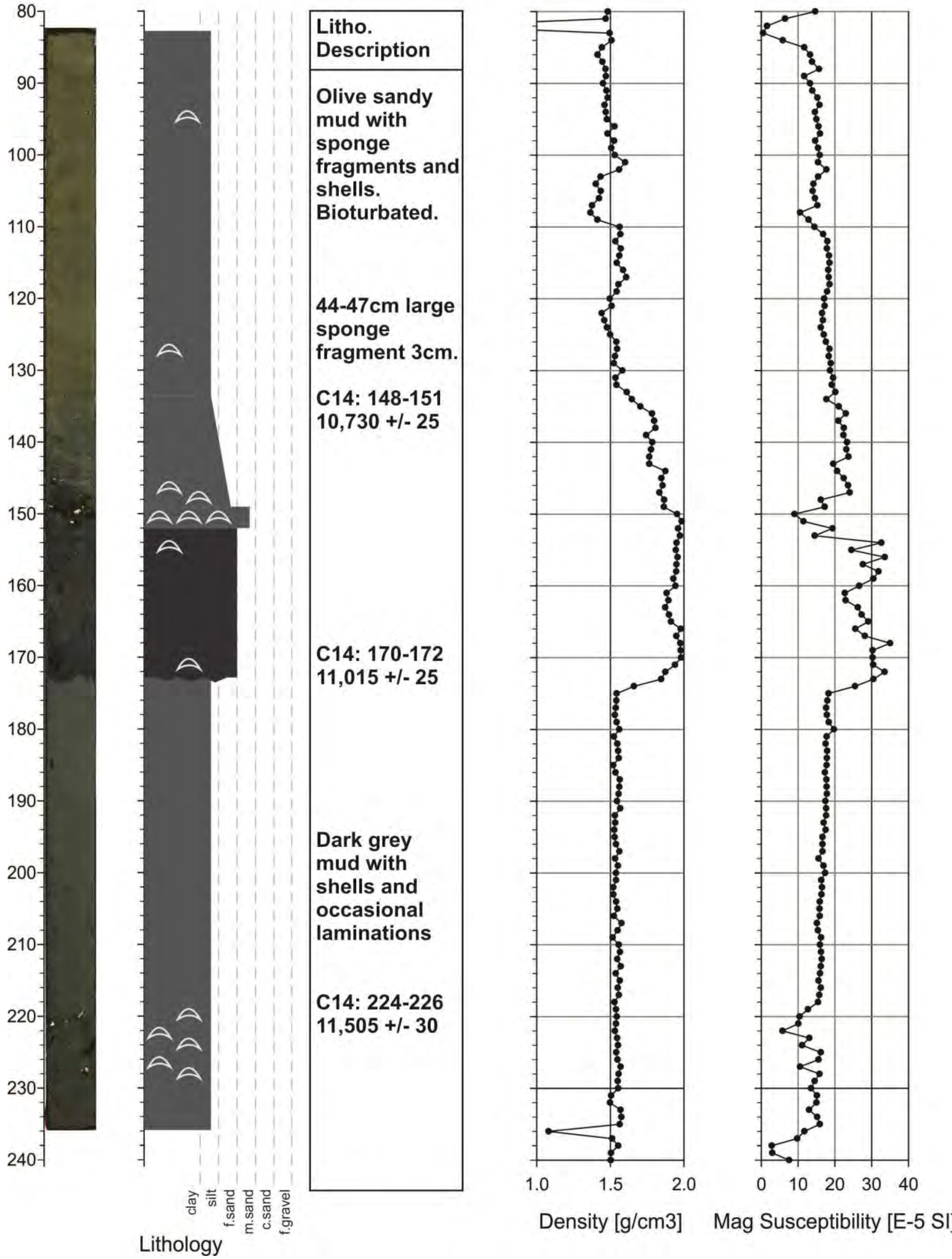


2015004PGC042 - Section 01

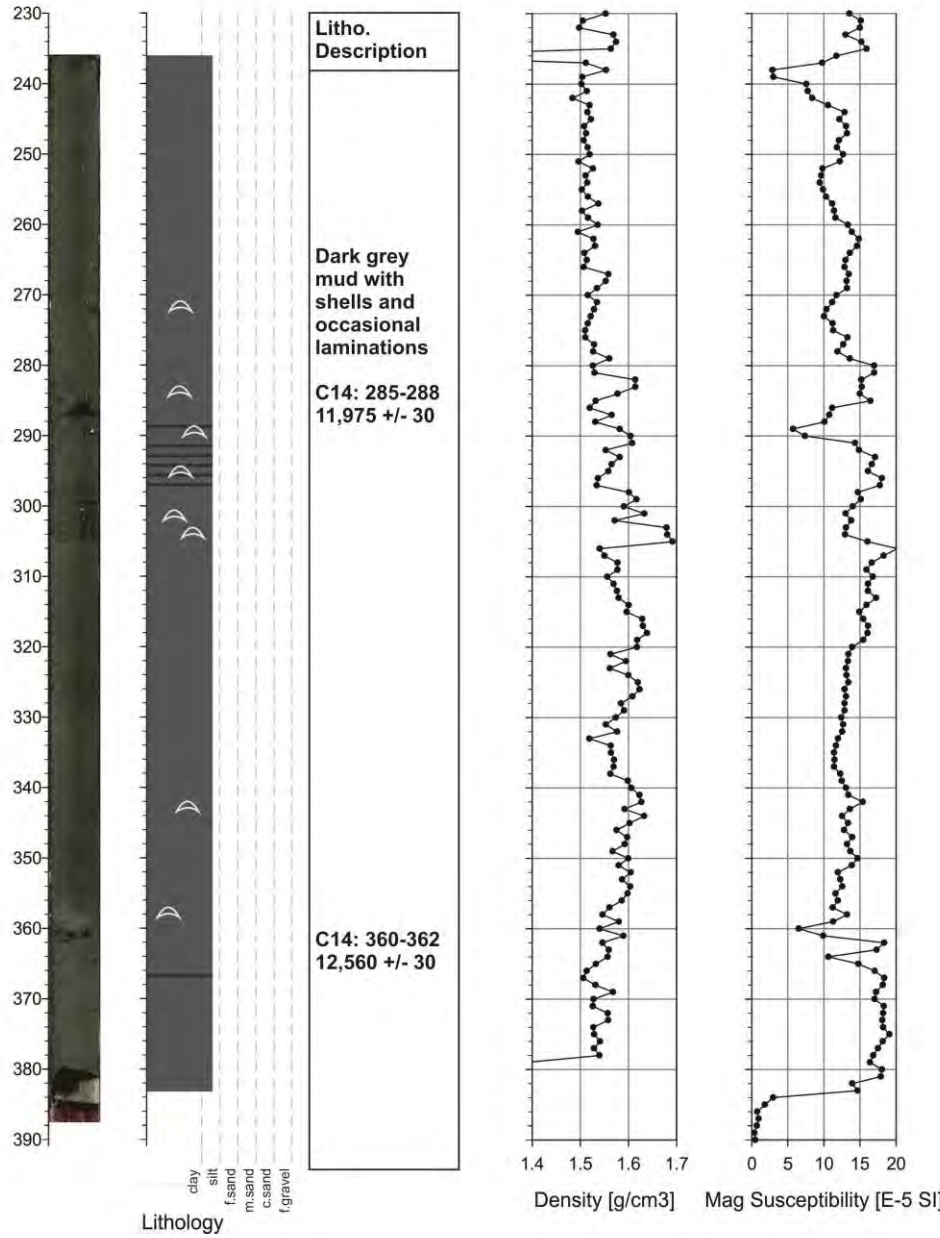


Litho. Description
Olive sandy mud with sponge fragments and shells. Bioturbated. 44-47cm large sponge fragment 3cm.

2015004PGC042 - Section 02



2015004PGC042 - Section 03



Appendix III

Seafloor Photos and Logs

Photo file too large to transmit via e-mail, but have been submitted to the USGS in Santa Cruz. Photos can be supplied upon request.

Camera Station 2015004PGC-14

PHOTO_NUM	PHOTO_LAT	PHOTO_LONG	PHOTO_GMT	WATER_DEPTH	DESCRIPTION_BY_PHOTO (UP TO 1 OF EACH PER PHOTO)
001	53.183183	-132.840238	003039	9999	shells on dark seabed; poor image
002	53.183183	-132.840238	003039	700	shells on dark seabed; poor image
003	53.183182	-132.840238	003049	702	sandy gravel with shells and shell debris
004	53.183902	-132.841332	005451	809	broken unudlatory seabed; rounded, eroded clay outcrops
005	53.183908	-132.841343	005457	690	broken sloping seabed; weak mudstone(?);
006	53.185132	-132.843175	010647	682	sandy gravel; biota
007	53.185627	-132.843930	011132	681	sandy gravel;
008	53.185633	-132.843950	011136	682	sandy gravel; slab of crust; clyptogena bivalves indicate possible vent comm?
009	53.186135	-132.844688	011627	824	gravelly sand on mudstone
010	53.186152	-132.844702	011635	781	sand on mudstone
011	53.186165	-132.844710	011641	774	cloud of sediment kicked up by camera; gravel bottom
012	53.186433	-132.845117	011918	685	thin sand on mudstone; colonized;
013	53.186438	-132.845133	011922	688	gravelly sand with minor shells
014	53.186673	-132.845470	012137	692	sand with minor gravel and shell debris
015	53.186967	-132.845922	012430	684	discontinuous sand on mudstone
016	53.187392	-132.846552	012832	683	mudstone surface, blocky and eroded.
017	53.187407	-132.846565	012839	692	fractured mudstone surface slope with mudstone blocks
018	53.187805	-132.847167	013236	714	thin sand on mudstone;
019	53.187817	-132.847185	013242	714	thin sand on mudstone; ledges and bedding planes - mudst.outcrop.
020	53.187830	-132.847210	013251	714	thin sand on mudstone; ledges and bedding planes - mudst.outcrop.
021	53.188027	-132.847507	013444	719	looking over mudstone ledge into scarp
022	53.188043	-132.847525	013451	735	looking down mudstone slope
023	53.188045	-132.847535	013456	697	looking over mudstone edge
024	53.188055	-132.847547	013500	696	looking down ledge into base of slope
025	53.188055	-132.847547	013500	696	looking down ledge into base of slope
026	53.188067	-132.847567	013508	697	looking down mudstone slope
027	53.188673	-132.848495	014106	703	gravel channel next to sand cover
028	53.188685	-132.848510	014113	673	gravel in a sand matrix

029	53.188900	-132.848807	014313	701	gravelly sand
030	53.189068	-132.849068	014450	693	sandy gravel
031	53.189080	-132.849098	014459	681	gravelly sand
032	53.189497	-132.849712	014901	684	mudstone beds with blocks
033	53.189515	-132.849728	014908	683	mudstone beds with blocks
034	53.189840	-132.850253	015225	685	mudstone beds looking down slope
035	53.189855	-132.850267	015231	686	mudstone beds looking down slope
036	53.189865	-132.850282	015238	686	mudstone beds looking down slope
037	53.190187	-132.850755	015540	687	sandy gravel veneer on mudstone
038	53.190192	-132.850768	015546	686	gravelly sand
039	53.190587	-132.851333	015930	692	gravelly sand veneer on mudstone
040	53.190590	-132.851350	015936	683	gravelly sand veneer on mudstone
041	53.190607	-132.851372	015944	666	gravelly sand veneer on mudstone
042	53.190737	-132.851567	020059	667	too dark
043	53.190905	-132.851803	020238	673	gravelly sand veneer on mudstone
044	53.190918	-132.851823	020244	663	gravelly sand veneer on mudstone; lots of angular mudclasts
045	53.191640	-132.852945	020949	651	gravelly sand on mudstone; large (1m) boulder
046	53.191837	-132.853212	021139	634	gravelly sand veneer on mudstone slope
047	53.192032	-132.853483	021329	634	mudstone slope
048	53.192038	-132.853490	021332	627	mudstone slope
049	53.192033	-132.853497	021334	627	mudstone slope
050	53.192052	-132.853525	021346	640	mudstone slope
051	53.192197	-132.853875	021558	708	gravelly sand veneer on mudstone and mudstone blocks
052	53.192202	-132.853890	021603	648	mudstone blocks and gravelly sand veneer
053	53.192228	-132.853913	021612	627	gravelly sand with shell frags
054	53.192653	-132.854428	021927	639	gravelly sand veneer on mudstone
055	53.192663	-132.854440	021935	700	cloud of sediment kicked up by camera;
056	53.193070	-132.854958	022305	646	mudstone beds looking down slope
057	53.193085	-132.854967	022309	659	mudstone beds looking down slope
058	53.193098	-132.854988	022317	653	cloud of sediment kicked up by camera;
059	53.193240	-132.855192	022440	742	mudstone slope

060	53.193258	-132.855197	022445	746	mudstone slope
061	53.193263	-132.855217	022451	746	mudstone slope
062	53.193277	-132.855237	022459	684	mudstone slope
063	53.193317	-132.855315	022525	695	mudstone blocks and gravelly sand veneer
064	53.193642	-132.855778	022830	686	eroded mudstone beds on slope with discontinuous gravell sand veneer.
065	53.193652	-132.855800	022838	668	eroded mudstone beds on slope with discontinuous gravell sand veneer.
066	53.193673	-132.855850	022854	692	mudstone with gravelly sand; sediment cloud

Camera Station 2015004PGC-31

PHOTO_NUM	PHOTO_LAT	PHOTO_LONG	PHOTO_GMT	WATER_DEPTH
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004	54.278140	-134.194718	010829	998
005	54.278142	-134.194718	010900	999
006	54.278137	-134.194725	010905	998
007	54.278137	-134.194727	010921	998
008	54.278137	-134.194975	011205	999
009	54.278137	-134.195345	011342	999
010	54.278138	-134.195368	011347	999
011	54.278137	-134.195763	011526	1003
012	54.278137	-134.195778	011529	1002
013	54.278148	-134.196187	011716	1007
014	54.278143	-134.196665	011919	1009

015	54.278140	-134.196710	011929	1011
016	54.278142	-134.197052	012053	1012
017	54.278142	-134.197072	012057	1013
018	54.278145	-134.197088	012102	1012
019	54.278150	-134.197355	012212	1014
020	54.278148	-134.197375	012218	1015
021	54.278148	-134.197632	012322	1015
022	54.278147	-134.197653	012328	1016
023	54.278140	-134.197877	012427	1018
024	54.278140	-134.198173	012540	1020
025	54.278142	-134.198418	012641	1023
026	54.278145	-134.198447	012648	1021
027	54.278138	-134.198483	012657	1023
028	54.278140	-134.198655	012746	1023
029	54.278142	-134.198673	012750	1024
030	54.278142	-134.198685	012755	1024
031	54.278138	-134.199037	012922	1027
032	54.278142	-134.199057	012928	1026
033	54.278140	-134.199075	012933	1027
034	54.278143	-134.199092	012936	1027
035	54.278115	-134.199452	013104	1028
036	54.278083	-134.199657	013201	1031
037	54.278080	-134.199680	013207	1031
038	54.278078	-134.199717	013217	1032
039	54.278062	-134.199835	013256	1031
040	54.278043	-134.200058	013408	1033
041	54.278048	-134.200083	013413	1034
042	54.278043	-134.200125	013427	1033
043	54.278027	-134.200217	013518	1034
044	54.278025	-134.200225	013525	1032
045	54.278023	-134.200217	013541	1033

046	54.278023	-134.200185	013613	1032
047	54.278020	-134.200080	013709	1028
048	54.278013	-134.200073	013714	1027
049	54.277995	-134.200038	013727	1028
050	54.277897	-134.199863	013826	1023
051	54.277887	-134.199853	013830	1023
052	54.277543	-134.199503	014132	1020
053	54.277392	-134.199347	014246	1018
054	54.277385	-134.199333	014252	1017
055	54.277233	-134.199212	014401	1016
056	54.277223	-134.199212	014405	1016
057	54.277075	-134.199058	014520	1013
058	54.276965	-134.198930	014618	1012
059	54.276848	-134.198838	014712	1013
060	54.276833	-134.198830	014719	1014
061	54.276778	-134.198760	014749	1011
062	54.276770	-134.198745	014755	1010
063	54.276622	-134.198617	014907	1009
064	54.276498	-134.198500	015008	1009
065	54.276480	-134.198500	015014	1010
066	54.276370	-134.198382	015111	1009
067	54.276358	-134.198373	015115	1009
068	54.276345	-134.198363	015121	1013
069	54.276245	-134.198253	015214	1009
070	54.276163	-134.198183	015254	1013
071	54.276145	-134.198188	015300	1008
072	54.276058	-134.198090	015345	1008
073	54.276047	-134.198070	015352	1008
074	54.276028	-134.198052	015400	1007
075	54.275968	-134.197937	015437	1006
076	54.275912	-134.197838	015516	1004

077	54.275895	-134.197835	015521	1004
078	54.275840	-134.197753	015557	1003
079	54.275832	-134.197748	015601	1003
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081	54.275748	-134.197643	015656	1003
082	54.275733	-134.197628	015704	1003
083	54.275660	-134.197523	015752	1001
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092	54.275428	-134.197290	020219	1001
093	54.275427	-134.197293	020227	1001
094	54.275423	-134.197293	020237	1001
095	54.275425	-134.197293	020258	1001
096	54.275425	-134.197295	020302	1001
097	54.275413	-134.197275	020311	1002
098	54.275387	-134.197283	020446	1001
099	54.275383	-134.197285	020452	1002
100	54.275388	-134.197288	020455	1002
101	54.275440	-134.197242	020537	1001
102	54.275548	-134.197142	020626	1000
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104	54.275650	-134.197028	020718	999
105	54.275662	-134.197032	020722	999
106	54.275737	-134.196952	020802	999
107	54.275747	-134.196947	020806	998

108	54.275820	-134.196870	020846	998
109	54.275825	-134.196853	020849	998
110	54.275842	-134.196843	020857	998
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112	54.275993	-134.196695	021011	998
113	54.276005	-134.196677	021016	998
114	54.276215	-134.196468	021204	997
115	54.276230	-134.196470	021210	997
116	54.276337	-134.196380	021305	996
117	54.276345	-134.196375	021308	996
118	54.276440	-134.196267	021354	996
119	54.276447	-134.196253	021358	996
120	54.276547	-134.196157	021449	997
121	54.276550	-134.196155	021451	997
122	54.276582	-134.196130	021505	997
123	54.276673	-134.196018	021554	996
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125	54.276787	-134.195907	021650	997
126	54.276800	-134.195902	021656	997
127	54.276872	-134.195835	021735	997
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130	54.276990	-134.195713	021835	997
131	54.277007	-134.195718	021839	997
132	54.277013	-134.195700	021844	997
133	54.277105	-134.195610	021930	996
134	54.277157	-134.195558	021958	996
135	54.277163	-134.195518	022007	997
136	54.277312	-134.195392	022112	995
137	54.277320	-134.195375	022117	995
138	54.277393	-134.195320	022153	996

139	54.277402	-134.195313	022158	996
140	54.277482	-134.195203	022242	996
141	54.277498	-134.195203	022247	996
142	54.277523	-134.195180	022259	996
143	54.277610	-134.195080	022349	996
144	54.277627	-134.195083	022354	996
145	54.277645	-134.195040	022407	995
146	54.277772	-134.194965	022459	996
147	54.277780	-134.194942	022504	994
148	54.277803	-134.194942	022513	995
149	54.277930	-134.194795	022621	994
150	54.277940	-134.194792	022627	994
151	54.277955	-134.194772	022637	994
152	54.278015	-134.194702	022712	993
153	54.278025	-134.194690	022717	993
154	54.278053	-134.194662	022730	994
155	54.278122	-134.194593	022802	993
156	54.278138	-134.194592	022807	992
157	54.278140	-134.194570	022811	992
158	54.278212	-134.194525	022841	993
159	54.278227	-134.194510	022849	992
160	54.278263	-134.194473	022938	991
161	54.278265	-134.194452	022945	991
162	54.278388	-134.194335	023046	989
163	54.278398	-134.194327	023050	990
164	54.278408	-134.194322	023055	990
165	54.278523	-134.194222	023151	989
166	54.278532	-134.194215	023155	990
167	54.278557	-134.194183	023209	989
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169	54.278708	-134.194038	023326	989

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171	54.278792	-134.193943	023408	987
172	54.278892	-134.193845	023453	988
173	54.278903	-134.193835	023458	987
174	54.278990	-134.193762	023539	987
175	54.279002	-134.193723	023549	987
176	54.279113	-134.193617	023647	987
177	54.279122	-134.193613	023650	987
178	54.279135	-134.193593	023701	987
179	54.279242	-134.193497	023757	986
180	54.279272	-134.193477	023808	986
181	54.279373	-134.193387	023850	985
182	54.279383	-134.193377	023855	985
183	54.279400	-134.193353	023903	985
184	54.279498	-134.193260	023955	984
185	54.279508	-134.193245	024001	985
186	54.279527	-134.193230	024010	983
187	54.279573	-134.193170	024036	983
188	54.279585	-134.193165	024041	983
189	54.279615	-134.193130	024057	983
190	54.279658	-134.193092	024118	983
191	54.279672	-134.193092	024123	983
192	54.279748	-134.193003	024207	982
193	54.279762	-134.193000	024213	982
194	54.279880	-134.192878	024309	982
195	54.279895	-134.192882	024314	982
196	54.279903	-134.192860	024320	981
197	54.279950	-134.192808	024344	982
198	54.279963	-134.192802	024349	981
199	54.280030	-134.192720	024422	981
200	54.280060	-134.192690	024435	981

201	54.280262	-134.192508	024621	981
202	54.280333	-134.192447	024654	981
203	54.280463	-134.192347	024756	982
204	54.280475	-134.192347	024802	982
205	54.280560	-134.192302	024845	983
206	54.280593	-134.192288	024900	983
207	54.280668	-134.192273	024937	984
208	54.280673	-134.192282	024942	984
209	54.280693	-134.192270	024953	984
210	54.280765	-134.192215	025033	985
211	54.280777	-134.192208	025039	984
212	54.280845	-134.192147	025123	985
213	54.280855	-134.192143	025133	985
214	54.280930	-134.192028	025222	985
215	54.280947	-134.192008	025227	986
216	54.281028	-134.191950	025333	985
217	54.281037	-134.191943	025339	986
218	54.281035	-134.191937	025432	985
219	54.281030	-134.191943	025439	985
220	54.281010	-134.192107	025530	985
221	54.281013	-134.192130	025536	985
222	54.281015	-134.192188	025552	986
223	54.281018	-134.192393	025643	986
224	54.281013	-134.192413	025649	986
225	54.280990	-134.192608	025743	987
226	54.280993	-134.192650	025753	987
227	54.281000	-134.192862	025848	988
228	54.280997	-134.192882	025854	988
229	54.281002	-134.193075	025941	989
230	54.281005	-134.193092	025947	989
231	54.280998	-134.193342	030047	990

232	54.280985	-134.193368	030055	990
233	54.280965	-134.193653	030211	991
234	54.280947	-134.194248	030438	996
235	54.280940	-134.194293	030449	996
236	54.280940	-134.194453	030534	998
237	54.280940	-134.194492	030543	998
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Camera Station 2015004PGC-37

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APPENDIX IV

Meeting Abstracts & Press Release

SSA Reno, Nevada Meeting Abstract (20-22 April 2016):

Determining Slip Along the Queen Charlotte-Fairweather Fault Zone

H. Gary Greene[1], J. Vaughn Barrie[2], and S. Nishenko[3], Kim Conway[2], Randy Enkin[2], James E. Conrad[4], Katherine L. Maier[4], and Cooper Stacey[2]

[1]Moss Landing Marine Labs, CA & SeaDoc Society Tombolo Mapping Lab, Orcas Island, WA
[2]Geological Survey of Canada, Sidney, B.C., Canada
[3]Pacific Gas & Electric Company, San Francisco, CA
[4]U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA

The Queen Charlotte-Fairweather (QC-FW) transform fault system separates the Pacific Plate from the North American Plate in the Pacific Northwest. It extends offshore from near the northern end of Vancouver Island, Canada through the Alexander Archipelago and into SE Alaska near Yakutat Bay. A joint Sitka Sound Science Center/Geological Survey of Canada cruise in 2015 investigated the southern part of this fault system, along the southern end of the 1949 Mw 8.1 Queen Charlotte Island earthquake rupture and north of the 2012 Mw 7.8 Haida Gwaii earthquake epicenter, using multibeam echo sounder bathymetric data, Knudson low power, 12 element, 3.5 kHz high-resolution Chirp seismic-reflection profiles, Benthos piston cores, IKU grab samples, and bottom camera photographs.

The surface expression of the QC-FW fault zone is well imaged offshore, west of the central Haida Gwaii Islands. Here, one of the larger submarine canyons along the western margin of Haida Gwaii heads at the shelf break and is tentatively named the "Cartwright Canyon". An approximate 800 m right-lateral offset occurs in the lower part of Cartwright Canyon where it intersects the fault zone, an ideal piercing point for determining slip. Gullies on the slope east of the fault zone are all truncated along faults and appear to be offset along a smeared bajada, or talus fans. Four gravity cores, two in the lower part of the canyon east of the fault zone and two within the lower offset part of the canyon west of the fault zone were collected, logged using a Multi-Sensor Core Logger, described, and sub-sampled for radiocarbon dating. The oldest sediment collected in these cores appears to be late Pleistocene in age (to be confirmed when dating is complete) and deposited during MIS stage 2 (~20 ka). Using this age and the 800 m offset we infer an approximate minimum slip rate of 40 mm/yr.

GeoHab Winchester, England Abstract (2-5 May 2016):

Are Seafloor Seeps, Mud Volcanoes, and Chemosynthetic Communities Significant Marine Benthic Habitats?

H. Gary Greene[1], J. Vaughn Barrie[2], and Kim Conway[2]
[1]SeaDoc Society, Orcas Island, WA & Moss Landing Marine Labs, CA USA
[2]Geological Survey of Canada, Sidney, B.C., Canada

During a recent scientific survey along the Queen Charlotte-Fairweather fault system, a transform plate boundary off British Columbia, Canada and Alaska, USA, seafloor fluid seeps, mud volcanoes, and chemosynthetic communities were discovered. Multibeam echosounder bathymetry, 3.5 kHz sub-bottom profile, 18 kHz sounder, piston core, grab sample, and bottom camera data indicate that significant volumes of fluid and gas is leaking into the water column along the southern half of the fault zone. While fluid seeps and mud volcanoes are ubiquitous along convergent plate margins, they are less so along passive and transform margins and these results suggest that such faulted landscapes could represent significant marine benthic habitats along the eastern Pacific Ocean.

We observed that a very large fluidized field marked by a newly discovered mud volcano, which displays a 700 m high gas plume from its 1,000 m crest located on the upper continental slope offshore Dixon Entrance (US/Canada boundary), harbors extensive chemosynthetic communities. These communities consist of *Calyptogena* spp. clams, *Vestimentiferan* spp. tubeworms, mussels, and *Beggiatoa* spp. bacterial mats. Carbonate slabs form hard substrate in an otherwise soft unconsolidated seafloor comprised of mud, glaciomarine sediments and boulders. The source and type of the gas is unknown, but we suspect that locally it is methane as indicated by the methanophillic organisms living near the vent sites. The presence of the chemosynthetic communities and carbonate substrate may play a major role in providing a forage habitat for fish, mammals, and other organisms. This habitat is most likely in flux and changing through time due to ephemeral fluid and gas escape. In addition, the seeps may contribute to greenhouse gases in the atmosphere and ocean acidification. Mapping these gas-rich habitats and identifying the associated benthic communities is critical to understanding the ecosystem value of these large areas.

GeoHab Winchester, England Abstract (2-5 May 2016):

Seeps and mud volcanoes – oxygen depletion along the Northwest Pacific coast of North America and implications for habitat

J. Vaughn Barrie[1] H. Gary Greene[2] Kim Conway[1] and
Frank A Whitney[3]

[1] Geological Survey of Canada, Natural Resources Canada, Sidney, B.C., Canada
[2] Moss Landing Marine Laboratories and SeaDoc Society Tombolo Lab, Orcas Island, Washington State, USA
[3] Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, B.C., Canada

Recent surveys along the Pacific Northwest from British Columbia into Alaska have identified more than 200 bubble clouds and gas plumes rising from 10 m to >700 m above the ocean bottom. The majority of the seeps are venting along faults in bedrock at depths between 70 and 1,000 m, suggesting methane is being lost from hydrocarbon or other organically-rich deposits. On the continental shelf some actively venting seeps form authigenic carbonate chimneys (mounds), with faunal assemblages different from that of surrounding soft substrate habitat and atypical of known cold seep communities. In addition, large plumes emanate from mud volcanoes along the plate boundary of the Queen Charlotte/Fairweather Fault system (Fig. 1), from Haida Gwaii into SE Alaska. These sites, located between 1,200 and 600 m, host extensive carbonate crusts and chemosynthetic communities of mussels and clams.

Since the volume of deep-sourced methane from these seeps is potentially very large, we assume the identified emissions are ongoing and have existed for a long period of time. The sites form unique benthic habitats along an extensively fished upper slope and continental shelf, however, the extensive release of methane may also limit the biologic diversity of regional shelf and coastal benthic habitats. These habitats are strongly delineated by oxygen availability in the NE Pacific; therefore, one has to consider how methane emissions might impact dissolved oxygen concentrations. For example, a 15 μM reduction in oxygen is observed on the 26.5 isopycnal surface near the highest density of seeps on the southern Vancouver Island Shelf. If methane release has and is presently impacting oxygen levels, how will benthic habitat be impacted with warming seas under climate change and the increased consumption of oxygen?

Figure 1: Multibeam image of mud volcanoes along the southern portion of the Queen Charlotte/Fairweather Fault off Haida Gwaii, British Columbia. Inset is an 18 kHz sounder profile of the continuously rising 300 m plume from one of the cones and a seabed photo showing the carbonate crust within the second volcanic cone (length of the compass and fin is ~ 40 cm).

STAR Nadi, Fiji Abstract (6-8 June 2016):

Assessing the seismic and tsunami hazards along a major transform plate boundary – the Queen Charlotte-Fairweather leaky transform fault system of Canada and Alaska

H. Gary Greene[1], J. Vaughn Barrie[2], Kim Conway[2], Daniel S. Brothers[3], James E. Conrad[3], Katherine L. Maier[3], and Stu Nishenko[4]

[1]Moss Landing Marine Labs, Center for Habitat Studies & SeaDoc Tombolo Mapping Lab, Orcas Island, WA
[2]Geological Survey of Canada, Pacific, Sidney, B.C., Canada
[3]U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA
[4]Pacific Gas & Electric Co., San Francisco, CA

A recent geophysical and geological investigation in the NE Pacific found that the Queen Charlotte-Fairweather fault system located offshore of Southern Alaska and western B.C. Canada is a unique tectonic transform plate boundary that appears to accommodate the entire relative plate motion between the Pacific and North American plates along a single fault trace. The investigation utilized previously collected multibeam echosounder bathymetry and newly collected 3.5-kHz Chirp sub-bottom profiles, piston cores, and seafloor towed camera photos to image the seafloor and determine offset along the fault zone. We found that the southern part of the fault zone leaks gas and fluids that produced substantial mud volcanoes (see figure) and which are associated with gully and canyon formation. Offsets of the canyons along a single trace of the fault are consistent and indicate that the plate boundary as expressed in the seafloor is a very linear feature. This leaky transform fault system exhibits areas of instability along the steep continental slope where high pore pressures associated with gas venting may facilitate mass wasting events that could trigger major submarine landslides and produce damaging tsunamis, adversely impacting population centers such as those located in Ketchikan, Alaska and Prince Rupert, B.C. Canada.

AGU San Francisco, California Abstract (12-16 December 2016):

The Queen Charlotte-Fairweather Fault Zone – The Knife-Edged Pacific-North American Plate Boundary

H. Gary Greene[1], J. Vaughn Barrie[2], Daniel Brothers[3], S. Nishenko[4], Kim Conway[2], Randy Enkin[2], James E. Conrad[3], Katherine L. Maier[3], and Cooper Stacey[2]

[1]Moss Landing Marine Labs, CA & SeaDoc Society Tombolo Mapping Lab, Orcas Island, WA
[2]Geological Survey of Canada, Sidney, B.C., Canada
[3]U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA
[4]Pacific Gas & Electric Company, San Francisco, CA

Recent investigations of the Queen Charlotte-Fairweather (QC-FW) Fault zone using multibeam echosounder bathymetric and 3.5-kHz sub-bottom profile data show that the fault zone is primarily represented by a single linear structure with small, localized pull-apart basins suggestive of transtension. Water column acoustical data imaged gas plumes concentrated along the fault zone with plume columns extending as much as 700 m above the crest of mud volcanoes. Piston cores indicate that the fault zone cuts hard-packed dense sands that have been dated as Pleistocene in age. The newly discovered fluids associated with the southern half of the fault zone and volcanic edifices with oceanic and continental plate petrologic affinities suggest that the QC-FW is a leaky transform system.

Two independent investigations, one in the north part and one in the central part of the fault zone, using two different types of piercing points, found that the slip rate along at least a 200 km length was consistent at between 40-55 mm/yr. since about 14 Ma, equivalent to the relative plate motion between the Pacific and North American plates in the NE Pacific region. We surmise that the QC-FW is accommodating most, if not all, of relative motion along a single primary strand without any detectable partitioning of motion onto other faults. This right-lateral strike-slip fault zone is expressed on the seafloor as a very straight feature that probably represents nearly pure strike-slip motion.

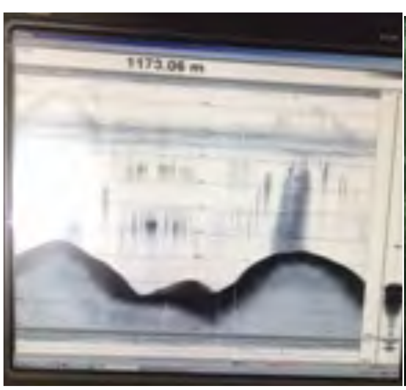
SSSC Press Release (25 September 2015):

SITKA SOUND
SCIENCE CENTER
834 Lincoln Street, Suite 200
Sitka, Alaska 99835
Admin Phone: 907.747.8878
Email: lbusch@sitkascience.org

Actively Venting Underwater Volcano Discovered In Dixon Entrance, Alaska

Sitka, Alaska, September 25, 2015: A US-Canadian cooperative cruise aboard the Canadian Coast Guard Ship *John P. Tully* investigating the Queen Charlotte-Fairweather fault system that extends from offshore of the northern part of Vancouver Island, Canada to the Fairweather Range in Southeast Alaska came upon an actively venting volcanic cone just north of the US Alaska-Canadian boundary, northwest of Haida Gwaii, near Dixon Entrance. The volcanic cone crests at 1,000 m water depth and exhibits multiple gas plumes rising about 700 m into the water column. Follow-up investigations are underway and the scientific team led by the Principal Investigators **Dr. H. Gary Greene (Sitka Sound Science Center) and Dr. Vaughn Barrie (Geological Survey of Canada)** and composed of scientists and technicians from the Geological Survey of Canada, the US Geological Survey and Sitka Sound Science Center and crew have sent down a camera to photograph the feature and have taken bottom grab samples to determine the activity and origin of the cone. Spectacular photographs have been taken showing the chemosynthetic clams and mussels living near the vents as well as other rare and exotic organisms. The volcano lies in what appears to be a volcanic field interspersed with landslides and other remarkable landforms.

The scientists and crew are excited about their find. This discovery suggests that fluids play a major role in facilitating the movement along the fault zone and that volcanic centers appears to be scattered along the entire length of the fault. Much more work needs to be done to refine the geologic interpretation, but the preliminary results from the cruise indicates that this fault zone that separates the North American Plate from the Pacific plate is actively leaking gas and fluids. **This work is funded by the United States Geological Survey through G15AP00034 awarded to the Sitka Sound Science Center.**



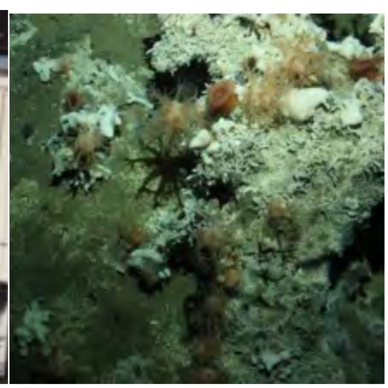


Figure 1. (left) Screen shot of the volcano from the scientific sounder. (right) Life at 1,000 m deep, where no light reaches the bottom organisms, requires food from other sources such as from chemicals seeping out vents or settling out in the water column. Organisms shown here are living near where fluids are seeping out of the newly discovered volcano.

For more information contact Tory O'Connell, Research Director, Sitka Sound Science Center voconnell@sitkascience.org, 907-747-8878 ext 7

APPENDIX V

Proposals Written Based on Outcomes of Study & Responses

NOAA-OAR-OER-2017-2004629 Pre-Proposal Submitted 20 September 2016:

Pre-Proposal – NOAA-OAR-OER-2017-2004629

Fluid Venting Along a Major Transform Plate Boundary

H. Gary Greene (greene@mlml.calstate.edu)
Moss Landing Marine Labs & Sitka Sound Science Center
Vaughn Barrie (vaughn.barrie@canada.gov)
Geological Survey of Canada, Pacific

The goals of this project are to determine how fluids affect fault movement within a major tectonic plate transform boundary, to map landslides and assess tsunami potential, and to characterize marine benthic habitats. These goals have merit in that they will advance the understanding of seismic hazards, tsunami generation, and benthic habitat characterization. This is a multidiscipline international effort to explore an uninvestigated part of the Pacific Ocean using the advanced technologies offered by OER, and communicate results to the public in a rapid and clear manner. Our cruise plans are to undertake bathymetric and geophysical surveys of the unexplored areas offshore of Dixon Entrance, Alaska and use data collected to select deep diving localities for observation and sampling of the seafloor using an ROV.

Recent exploration of the Queen Charlotte-Fairweather fault (QC-FW) system suggests that this major transform tectonic plate boundary is unique. Its uniqueness stems from the apparent indication that the entire relative plate motion between the Pacific Plate and the North American Plate at the NE margin of the Pacific Ocean is accommodated along what appears to be a single fault trace; in other words, no partitioning of motion onto other faults appears to be taking place as observed on other transform fault systems (e.g., the San Andreas Fault Zone). In addition, the QC-FW fault zone is a "leaky transform" with past magmatic venting in the north (Brew et al., 1969), which formed Mt. Edgcumbe and offshore volcanic cones in Alaska (Greene et al. 2007), and active fluid venting in the south, which forms mud volcanoes and produces habitat for chemosynthetic communities in Alaska and British Columbia, Canada. The principle question, therefore, is: "do fluidized transform fault zones constrain plate motion to a single fault trace?"

In addition, our recent investigation of the QC-FW system suggests that high pore pressures associated with gas venting may facilitate mass wasting along the upper slopes east of the fault system and could trigger a major submarine slide that may produce a damaging tsunami, adversely impacting population centers such as those located in Ketchikan, Alaska, Sitka, Alaska and Prince Rupert, B.C. Canada. Therefore, a major goal of this project is to map and investigate the central Queen Charlotte-Fairweather transform fault zone to determine if and how fluids facilitate movement along a single fault that appears to be accommodating the entire relative motion between the Pacific and North American plates. Additional goals are to map and examine mass failures on the slope and assess the tsunami potential of the region and to study the chemosynthetic communities and benthic habitats associated with the fault zone.

The goals of this proposed study have merit in that they will advance the understanding of seismic hazards and tsunami generation along a unique transform boundary where considerable fluid venting is occurring and partitioning of plate motion appears not to be present.

Our interest is a multidiscipline international concern to explore an unknown part of the Pacific Ocean and to communicate our results to the public in a rapid and clear manner. We will approach this research interest by collecting, processing and interpreting multibeam bathymetry, backscatter, and 3.5 kHz sub-bottom profiles to select ROV sampling sites. An international team of scientists from the Canadian Geological Survey, the USGS and other organizations will participate in this research.

In summary, the major project goal is to image the seafloor and sub-surface stratigraphy offshore Dixon Entrance in order to map the seafloor in the highest resolution possible for delineation of geomorphic features such as the surface expressions of faults, mud volcanoes, and landslides and to compare fluid conduits with faults. We surmise that faults of the system are acting as conduits for the fluids, but wonder how friction along the fault planes are being reduced, if at all, by the presence of the fluids. Another goal would be to map and examine mass failures on the slope and assess the tsunami potential of the region. Finally, further study of the chemosynthetic communities and habitat characterization is proposed by examining and sampling carbonate crusts, collecting fluid samples from vent plumes, and biological specimens for taxonomic and DNA analyses.

Response:

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
OFFICE OF OCEANIC AND ATMOSPHERIC RESEARCH
1315 East-West Highway
Silver Spring, Maryland 20910

October 31, 2016

Dr. H. Gary Greene
Moss Landing Marine Labs &
Sitka Sound Science Center
142 Anchor Rock Ln.
Eastsound, WA 98245

Dear Dr. Greene:

NOAA's Office of Ocean Exploration and Research (OER) appreciates your submission of the pre-proposal entitled, "Fluid Venting Along a Major Transform Plate Boundary."

Your pre-proposal was assessed by OER using the criteria and factors identified in the Ocean Exploration FY2017 Federal Funding Opportunity (FFO) and, based on this assessment, **we discourage you from submitting a full proposal** for the following reasons:

- The project's objectives do not align with OER's priorities defined in the FFO.
- As written, the project does not provide a documented justification that required ship or other seagoing assets will be available.

The above recommendation is intended to provide you with OER's best assessment of the likelihood of competitive success of the project described in your pre-proposal. This recommendation does not preclude submission of a full proposal.

If you have questions, you may address them to the Proposal Manager, telephone (301) 734-1002 or e-mail oer.ffo2017@noaa.gov. Please include your pre-proposal number, which is **OERFY17_048_Green**, in any communications.

Sincerely,

Alan P. Leonardi, Ph. D.
Director, NOAA Office of Ocean Exploration & Research

Printed on Recycled Paper

THE ASSISTANT ADMINISTRATOR

Schmidt Oceanographic Institute (SOI) *Falkor* 2018 Expression of Interest (Submitted 10 November 2015)

Tectonic Mischief Along A Transform Margin

Goals – The QC-FW fault system is the major structural feature that extends from near the northern end of Vancouver Island, Canada to well into the bite of the Gulf of Alaska. This system represents a major transform boundary that separates the Pacific Plate from the North American Plate. Approximately 75% of the system is located offshore in deep water and far from land. In most locations the continuity of the QC-FW is not well constrained and the presence of ancillary faults are basically unknown for most of the fault system's length. Recently we discovered a new mud volcano and multiple gas plumes that indicate that gas expulsion and fluid flow is prominent along most of the fault zone, suggesting a very leaky transform fault.

A major goal arising from our discovery of the gas and fluid vents is to determine how such fluids effect fault movement and indicates tectonic stress within a transform boundary. We surmise that faults of the system are acting as conduits for the fluids, but wonder how friction along the fault planes are being reduced, if at all, by the presence of the fluids. Another goal would be to map and examine mass failures on the slope and assess the tsunami potential of the region. Finally, further study of the chemosynthetic communities and habitat characterization is proposed. These goals will advance the understanding of seismic hazards and tsunami generation.

Strategic Interest of SOI – Our interest is a multidiscipline international concern to explore an unknown part of the Pacific Ocean and to communicate our results to the public in a rapid and clear manner, as outlined in the Strategic Focus of SOI. Using the advanced technologies aboard the *Folkor* we intend to process and interpret all data collected on board and to complete our maps and initial report writing before disembarking the vessel. Students will be involved.

Principal Investigators:

H. Gary Greene
Moss Landing Marine Labs – SeaDoc Society Tombolo Lab, Orcas Island, WA, and Friday Harbor Labs, University of Washington (greene@mlml.calstate.edu; phone: 831-332-3627)

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Sitka Sound Science Center, Sitka, Alaska

Key Fields of Research:

Geology – tectonic processes, seismicity, mass wasting and tsunami generation, fluid flow, chemosynthetic communities, and marine benthic habitat characterization.

Targeted Geographical Region:

Offshore northern British Columbia Canada-southern SE Alaska, along the Central Queen Charlotte-Fairweather (QC-FW) transform fault system on the continental slope offshore of Haida Gwaii, Canada and Dixon Entrance to Sitka Sound, Alaska USA. Research is dependent upon undertaking the study in this geographical region, as much of the investigation will be exploration.

Ship Time and Major Equipment Requested:

Approximately three weeks of RV *Falkor* ship time is requested to undertake detailed wide-swath multibeam echosounder (MBES) surveys along the central part of the QC-FW fault system and associated conjugate or splay faults. Both shallow water (continental shelf depths) and deep-water (upper continental slope depths) MBES systems aboard the *Falkor* are desirable for this work. In addition, follow up surveys using the 4500 m deep diving ROV aboard the ship is requested to photograph and sample (sediment and biology) targets identified in the MBES surveys. If available, UAVs could be used to map specific areas along the faults and to sense fluids emanating from fluid vents.

Tentative Cruise Plan and Equipment Needed – From Seattle, WA., Sidney or Vancouver, B.C. sail north to northern Haida Gwaii and work north to Sitka, Alaska, or start at Sitka and sail south to the ports in the Pacific NW. Primary equipment needed would be the MBES systems, ROV, computers with GIS capabilities and sub-bottom profilers. We desire to have the ability to readily construct and print maps as well as generate illustrations and models that can be used to describe the results of the expedition.

Supplemental Equipment and Funds – Corers and benthic grab samplers can be provided, as well as portable computers with processing software. Labs onshore and travel funds to be provided by home institutes, grants, private or personal funds.

Suggested Reviewers – Dr. Guy Cochrane, USGS (gcochrane@usgs.gov); Dr. Waldo W. Wakefield, NOAA, NMFS (waldo.wakefield@noaa.gov); Dr. Sandy Willie-Echeverria, UW Friday Harbor Labs, University of Washington (zmseed@u.washington.edu); Professor Stephan A. Graham, Stanford University (sagraham@stanford.edu); Dr. Phil Hogan, Fugro Consultants (PHogan@fugro.com

Response:

On Apr 22, 2016, at 6:07 AM, Leonard Pace <lpace@schmidtocean.org> wrote:

Dear Dr. Greene,

Below, please find the confidential feedback and resolution for the Expression of Interest entitled, “Tectonic Mischief Along A Transform Margin” that we received from you.

Reviewer 1 Comments: Improved mapping of Queen Charlotte-Fairweather fault system would add tremendously to both knowledge of Northwestern Pacific tectonics and earthquake potential. Understanding this large strike-slip fault system better may increase knowledge of how segments of hazardous AK megathrust faults are loaded over time. Well-proven and appropriate methods would be used for data acquisition; leverage for obtaining sediment and biological samples can optimize scientific returns. The plan for shipboard processing and data release is strong. This is a do-able, stand-alone project that could have a strong outreach impact if a full proposal includes development of a robust plan for public communication.
Reviewer 1 Grade: A

Reviewer 2 Comments: The proposal is developed around the interesting idea that the release of gas and fluids from larger depth affects the slip behavior of this seismogenic fault zone. The data sharing and outreach aspects of this proposal are not sufficiently developed, but it is otherwise a very strong science plan.
Reviewer 2 Grade: A-

Reviewer 3 Comments: The PIs are keen to generate maps of the seafloor, sub-bottom profiles and graphical representations of their observations while underway or before disembarkation. Using ROV capabilities should allow the PIs to prioritize efforts to sample, characterize biological communities and/or generate sub-bottom profiles. This is definitely a strength.

•It does not seem that the PIs aim to test new capabilities on this expedition.

•Constraints on the geometry of the offshore fault system are certainly important. The PIs note recent observations of a mud volcano and multiple gas plumes along the trace of the fault system. These are promising findings and certainly warrant additional work. There is not much attention to specific parameters that will be emphasized when fluid vents are detected. Will samples be collected and analyzed onboard? Certainly vent sites and mud volcanoes will be mapped in the context of all other expressions of the fault system (e.g., scarps, pull-apart basins, biological communities). The PIs have not elucidated what they expect to find that will shed light on tsunami hazards. Presumably if mass-transport deposits are discovered, some effort to understand their geometries, volumes, lithologies, and possibly source areas would be undertaken.

•The details of how the data products generated while underway will be shared are not described to fully understand. Completing an initial report volume akin to that required by IODP is an excellent goal. Sharing such a volume, including data tables and maps, would be a plus.

•Providing real time video from ROV surveys to the public would be great, although it is not described in the expression of interest. The coastal communities in the region might find an expedition that aims to explore the widely known, but not well understood, fault system very engaging.

Summary: This expression of interest is aimed at the offshore portions of the Queen Charlotte-Fairweather transform fault. The PIs suggest that more extensive research in this region hinges on preliminary data collected by the proposed expedition. They describe recent observations that suggest mud volcanism and fluid venting along much of the fault system trace. These kinds of targets lend themselves to further investigation by the Falkor. They also might well set the stage for further study by other programs that require more data before committing resources (e.g., IODP).
Reviewer 3 Grade: A-

Average Grade: 4.28 out of 4.83 – Excellent (A-)

Resolution: Schmidt Ocean Institute would like to invite a full proposal for this project that would address any shortcomings identified by the reviewers above. Please use the linked guidelines to prepare and submit a proposal to Schmidt Ocean Institute. Additionally, please reply to this email to indicate whether or not you intend on preparing a full proposal in response to this invitation.

Geographical Area of Operation: The highest geographic density of research sites requested in the successful Expressions of Interest that we reviewed this year occurs in the eastern Pacific Ocean midlatitudes and northeast Pacific Ocean. Schmidt Ocean Institute selected this region as an operational area for RV Falkor in 2018. We understand this region of operations is generally acceptable for your project. Please note that Schmidt Ocean Institute will only be able to support this project if the proposed target research sites fit within the identified area of RV Falkor operations in 2018. Please do not hesitate to contact us to discuss any related questions or concerns.

For Your Consideration: Schmidt Ocean Institute's 4,500 meter depth capable Remotely Operated Vehicle is currently undergoing final integration and testing, and will be available to support oceanographic research in 2018. SOI Board of Directors requested that RV Falkor seagoing research program be structured to maximize the utilization of this new ROV. Accordingly, ROV use will be considered as a strong positive factor during SOI's internal proposal evaluations.

Please let me know if I can provide any additional information or address any related questions.

Sincerely,
Leonard

Direct link to Schmidt Ocean Institute Proposal Preparation Guidelines:
https://docs.google.com/document/d/1IdVhHjJ4PM4LuWrgMJ6G0iKrf0PiKSP4Sw9--Pi_t6k/edit?usp=sharing

Schmidt Oceanographic Institute (SOI) *Falkor* 2018 Expression of Interest (Submitted 17 June 2016)

1. Proposal Identification and Overview - SOI

Title of Proposal

Tectonic Mischief Along A Transform Margin

Key fields of research pertinent to the proposed study

Marine Geology & Geophysics

Executive Summary

A major goal of this project is to map and investigate the Queen Charlotte-Fairweather transform fault zone to determine if and how fluids facilitate movement along a single fault that appears to be accommodating the entire relative motion between the Pacific and North American plates. Additional goals are to map and examine mass failures on the slope and assess the tsunami potential of the region and to study the chemosynthetic communities and benthic habitats associated with the fault zone.

The goals of this proposed study have merit in that they will advance the understanding of seismic hazards and tsunami generation along a unique transform boundary where considerable fluid venting is occurring and partitioning of plate motion appears not to be present.

Our interest is a multidiscipline international concern to explore an unknown part of the Pacific Ocean and to communicate our results to the public in a rapid and clear manner, as outlined in the Strategic Focus of SOI. We will approach this research interest by collecting, processing and interpreting multibeam bathymetry, backscatter, and sub-bottom profiles using the advanced technologies aboard the *Falkor* to select ROV sampling sites. Data management will be through the Geological Survey of Canada and the U.S. Geological Survey.

Corresponding Principal Investigator

Title
Professor
First Name
H. Gary Greene
Last Name
Greene

Institutional Affiliation(s) and Country
Sitka Sound Science Center (SSSC), Alaska, Center for Habitat Studies, Moss Landing Marine Labs (MLML, San Jose State University), Friday Harbor Labs (University of Washington), and SeaDoc Society (University of California, Davis), USA

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Research Team

List all Principle Investigators with their respective institutional affiliation and country

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List all Co-Principle Investigators with their respective institutional affiliation and country

Dr. J. Vaughn Barrie, Geological Survey of Canada (GSC), Pacific, Natural Resources Canada, PO Box 6000, 9860 West Saanich Road, Sidney, B.C., V8L 4B2, Canada

List all other participating research team members with their institutional affiliation and country

Dr. Daniel Brothers, US Geological Survey (USGS), Santa Cruz, CA USA
Dr. Katherine Maier, USGS, Santa Cruz, CA USA
James Conrad, USGS, Santa Cruz, CA USA
Dr. Brian Todd, GSC, Atlantic, Canada
Dr. Peter Harris, GRID-Arendal, Norway
Dr. Terje Thorsnes, Geological Survey of Norway (GSN), Norway

Prof. Jens Greinert, GEOMAR, Germany
Dr. Gary McMurtry, University of Hawaii
Dr. Stewart Nishenko, Pacific Gas & Electric Co., San Francisco, CA USA
Kim Conway, GSC, Pacific, Canada,
Peter Neelands, GSC, Pacific, Canada
Kim Picard, Geoscience Australia, Canberra
Student (TBD)
Technician (TBD)

Suggested Reviewers

Dr. Guy Cochrane, USGS (gcochrane@usgs.gov)
Dr. Waldo W. Wakefield, NOAA, NMFS (waldo.wakefield@noaa.gov)
Dr. Sandy Willie-Echeverria, UW Friday Harbor Labs, University of Washington (zmseed@u.washington.edu)
Professor Stephan A. Graham, Stanford University (sagraham@stanford.edu)
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Dr. Robert Embley (Robert.W.Embley@noaa.gov)

3. Project Description

a. Executive Summary

The **goals** of this project are to determine how fluids affect fault movement within a major tectonic plate transform boundary, to map landslides and assess tsunami potential, and to characterize marine benthic habitats. These goals have **merit** in that they will advance the understanding of seismic hazards, tsunami generation, and benthic habitat characterization and have **relevance to SOI strategic interests** in that this is a multidiscipline international effort to explore an uninvestigated part of the Pacific Ocean using the advanced technologies aboard the *R/V Falkor*, and communicate results to the public in a rapid and clear manner. Our **cruise plans** are to undertake bathymetric and geophysical surveys of the unexplored areas offshore of Dixon Entrance, Alaska and use data collected to select deep diving localities for observation and sampling of the seafloor using SOI's 4,500m ROV. **Data acquisition and management** will be in cooperation with the GSC and USGS, and made publically available through their data management systems. A multitude of **outreach opportunities** will be utilized in addition to SOI's efforts and will include presentation of data and results from the cruise internationally through web sites and interactive links at GRID-Arendal and the GSC, and locally through SSSC, GSC, and USGS.

b. Research hypotheses and questions

Recent exploration of the Queen Charlotte-Fairweather fault (QC-FW) system suggests that this major transform tectonic plate boundary is unique. Its uniqueness stems from the apparent indication that the entire relative plate motion between the Pacific Plate and the North American Plate at the NE margin of the Pacific Ocean is accommodated along what appears to be a single fault trace; in other words, no partitioning of motion onto other faults appears to be taking place as observed on other transform fault systems (e.g., the San Andreas Fault Zone). In addition, the QC-FW fault zone is a "leaky transform" with past magmatic venting in the north (Brew et al., 1969), which formed Mt. Edgcumbe and offshore volcanic cones in Alaska (Greene et al. 2007), and active fluid venting in the south, which forms mud volcanoes and produces habitat for chemosynthetic communities in Alaska and British Columbia, Canada. The principle question, therefore, is: "do fluidized transform fault zones constrain plate motion to a single fault trace?"

In addition, our recent investigation of the QC-FW system suggests that high pore pressures associated with gas venting may facilitate mass wasting along the upper slopes east of the fault system and could trigger a major submarine slide that may produce a damaging tsunami, adversely impacting population centers such as those located in Ketchikan, Alaska, Sitka, Alaska and Prince Rupert, B.C. Canada.

We have developed several working hypotheses based on some previous work and our previous studies:

- Fluid seeps and vents are constrained to a narrow within the QC-FW fault zone and thus facilitate all of the relative plate motion between the Pacific and North American Plate in this region (Bufe, 2005; Bonini, 2012; Barrie et al., 2013)
- Large potentially tsunamogenic landslides exist on the upper continental slope offshore Dixon Entrance and are mobilized by increased poor pressures from venting (Greene et al., 2002, 2005; Eichhuble et al., 2001, 2002)
- Vent fluids are sourced from hydrocarbon reservoirs at depth, buried biogenic decomposing organic matter buried under a thick sediment load, or from clathrates (disassociation of frozen hydrates) at depth (Dimitrov, 2002, Paull et al., 2008, 2015a,b)
- Benthic chemosynthetic community habitats are being formed from venting and are ubiquitous along the QC-FW fault zone (Levin et al., 2016)
- Mud volcanoes result from venting along the QC-FW fault zone (Duchesne et al., 2011; Bonini, 2012)
- Submarine canyons and gullies along the QC-FW fault zone form from fluid venting (Greene et al. 2002, Harris et al., 2014)

- Fluid and gas venting along the fault zone contribute substantially to climate change and ocean acidification (Kopf, 2003: Sauter, 2006)

Understanding the process of plate motion and the cause for earthquakes and landslides along active faults in the submarine environment is important to the prediction of such events occurring in the future in the region of study and elsewhere where active faults are located. In addition, learning about the formation of deep marine benthic habitats provides information useful in protecting the habitats and understanding their synergy with benthic and pelagic organisms. Although the overall study is a geohazards deterministic exercise in an unexplored region of the Pacific Ocean, an importance in its own right, the data collected will have tremendous importance in the probabilistic evaluation of seismic and tsunami potential in general. Measurement of the pH of the water around seeps should be useful in determining influences on ocean acidification and estimation of the amount of gas venting has the potential of quantifying a local natural contribution to greenhouse gas emissions.

c. Strategy and methodology:

The major project goal is to image the seafloor and sub-surface stratigraphy offshore Dixon Entrance in order to map the seafloor in the highest resolution possible for delineation of geomorphic features such as the surface expressions of faults, mud volcanoes, and landslides and to compare fluid conduits with faults. We surmise that faults of the system are acting as conduits for the fluids, but wonder how friction along the fault planes are being reduced, if at all, by the presence of the fluids. Another goal would be to map and examine mass failures on the slope and assess the tsunami potential of the region. Finally, further study of the chemosynthetic communities and habitat characterization is proposed by examining and sampling carbonate crusts, collecting fluid samples from vent plumes, and biological specimens for taxonomic and DNA analyses.

A subsidiary goal is to collect bathymetric, seismic-reflection profile, and water column data along the QC-FW in transit from the Seattle/Bellingham/Vancouver/Sidney mobilization site to our primary Dixon Entrance survey area along the QC-FW in order to obtain data that shows active seeps, gas plumes, landslides and canyons. These data will be used to confirm slip rate on the QC-FW fault zone and to quantify the vent sites.

To achieve our goals we intend to collect data using both Kongsberg 710 and EM 302 multi-beam echo sounder (MBES), single beam Kongsberg EA 600 sounder, the Simrad EK60 fishery research sounder, the high definition omnidirectional fishery 114 kHz sonar, and the Knudsen CHIRP 3260 12 kHz sub-bottom profiler systems aboard the *R/V Falkor* to image gas plumes in the water column, the seafloor, and sub-surface stratigraphy. A USGS mini-sparker high-resolution seismic-reflection profiling system will be installed aboard the *Falkor* for the purpose of obtaining relatively deep-penetration sub-bottom data. Based on the interpretations of these data we will select sites for observation and sampling using the 4,500 m ROV aboard the *R/V Falkor*, outfitted with a pH collector/sensor, DOMS Model 12-1 mass spectrometer and flow meter (see

Appendix I for details), gas collection bottles[1], and push or vibra cores that can collect data to measure the in situ chemical components of the gas plumes and seep sites identified in the geophysical survey data. A Bubble Box – stereographic system for visual bubble size measurements important for hydro-acoustic flow rate estimates and a Gas-Quant-2 system, small tripod with horizontally looking multibeam system for gas release activity measurements and flux quantifications (GEOMAR, see Appendix I for details), will be used and placed with the ROV. Video of the seafloor, cores, carbonate and biological samples collected by the ROV will be used to determine fluid sources, rate of venting, and refine the interpretation of the geomorphic features mapped (gas and fluid samples will be sent to an external lab for analyses at GEOMAR and mass spectrometer data at University of Hawaii [UH] with initial analyses being done onboard ship).

In addition, if available, we can use any CO_2 sensors aboard the *Falkor* to determine presence of the gas at or near the sea surface overlying vents that appear to have a plume that may reach the surface. Towed shipboard magnetic and gravity data would be collected using the *Falkor*'s magnetometer and gravimeter, if available, to determine if the mud volcanoes are truly of mud or if they are underwater pingos or volcanic edifices.

The research and cruise plan proposed here will effectively address the research questions and hypotheses by providing geophysical, geological and biological data in a remote unexplored region of the Pacific Ocean poorly investigated in the past. All the data collected by the *Falkor* will provide new insights into the geological, climatological, and biological processes at work in the region. Specifically, the seafloor images, sub-surface stratigraphy, and water column data will provide the answer to the distribution and concentration of vents, while detailed imagery in the Dixon Entrance survey area will provide data that can be used to identify past and potential landslides that may have, or may stimulate tsunamis. Chemical samples sensed using the ROV should provide data to indicated source areas of fluids and gas (e.g., helium originating from mantle depths), and thus indicate depth to source areas and their position in relation to the seismogenic zone. Relationship of the fluid source areas with the seismogenic zone will be used to estimate the fault surface area that is fluidized and thus could have a reduced friction of motion, facilitating fault creep or rupture. Seafloor sediment samples collected by the ROV will be used to date crusts and sediments in order to determine rate of deposition and history of fluid flow. Observations and sampling of chemosynthetic communities around vents and other organisms will provide answers to the extent of marine benthic habitats and if the organisms they host are unique. Finally, acoustic mapping, observation, sampling, and estimation of gas venting along the QC-FW fault system will provide data useful in determining the amount of greenhouse gas entering the water column and seeping into the atmosphere. Radiometric dating for age determination will be done post-cruise on promising substrate samples.

d. Related projects and competitive landscape:

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[1] *Presently in discussions with MBARI (Charlie Paull) and GEOMAR (Jens Greinert) on types of bottles to use and attach to the ROV.*

This proposed SOI investigation builds upon a geophysical and coring study of the QC-FW fault system undertaken in September 2015 that was supported by the USGS National Earthquake Hazards Reduction Program (NEHP) in cooperation with the Geological Survey of Canada (GSC) using the *CCGS Tully*. During this study we discovered a new mud volcano and extensive fluid and gas seeps along the fault zone. From this work it became apparent that we were dealing with a unique plate boundary that could be a leaky transform fault zone. This serendipitous discovery along with the evidence of total relative plate motion being taken up along a single fault stimulated our interest in pursuing a study of the relationship of fluid flow and slip rate along a major plate boundary. We are also planning on obtaining additional piston cores and shallow water bathymetric data using GSC and NOAA resources, but these efforts will be secondary and supplemental to the work proposed here.

While fluid venting and mud volcanoes are ubiquitous along convergent plate margins (Tinivella and Giustiniani, 2013, and references therein; Depreiter et al., 2005, and references therein) they are less so along pure strike-slip transform margins where little or no convergence takes place. Compression by the down-going slab of subduction zones and off scrapping force inter-formational fluids from the overlying plate, which produce vents, pockmarks, and mud volcanoes on the seafloor (Depreiter et al., 2005, and references therein). Along the very southern portion of the QC-FW 20^{o} oblique convergence becomes purely strike-slip at approximately 53^{o} N with a change in margin trend (Hydman and Ellis, 1981; Hydman and Hamilton, 1993; Barrie et al., 2013). From here north a very straight and lengthy transcurrent fault zone occurs with little or no transpression or transtension taking place, the presence of fluid vents and mud volcanoes indicate a different and unique process may be at work here. This observation along with the evidence (Greene et al., 2016) that indicates the entire relative slip rate between the Pacific and North American Plate is taking place without partitioning of movement along other faults within the system, unlike that found in other transform boundaries, is unique. The region of study is particularly unique in that several critical environmental processes can be studied from one survey, which entails determining the seismic hazard of a major plate boundary, the potential for tsunamigenic landslides, benthic habitat characterization, and natural contribution to modern climate change (Kopf, 2003; Sauter et al., 2006).

Success of this proposed study does not depend upon related research, but it builds upon what has been newly discovered and can be supplemented by planned and potentially future investigations. The study is pioneering, stands alone and by itself will provide valuable data that will contribute to a new and unique understanding of geological and biological processes associated with a major tectonic plate boundary.

e. Intrinsic scientific value of project:

The basic intrinsic scientific value of the project is that a remote and poorly surveyed, yet tectonically active area of the Pacific Ocean will be explored in detail. We anticipate the construction of the first high-resolution bathymetric, geologic and biologic (structural, geomorphic, tectonic, habitat) maps of the seafloor along the central tectonic plate boundary of the NE Pacific. In addition, we anticipate obtaining seafloor substrate and vent fluid samples to be used in determining ages of sediment/crusts, source of fluids, and identification of benthic habitats based on the organisms collected. Overall we anticipate being able to report upon unique tectonic processes that are occurring along the QC-FW fault system.

Our interest is a multidiscipline international concern to explore an unknown part of the Pacific Ocean and to communicate our results to the public in a rapid and clear manner, as outlined in the Strategic Focus of SOI. In a sense this project is pure exploration (pioneering) and all data collected will provide new insights and hypotheses into the geologic and tectonic processes associated with a major tectonic plate boundary that can be used by the global scientific community to study similar boundaries and processes elsewhere. The assessment of geohazards in the region, specifically seismic and tsunamigenic hazards will provide information on the potential for adverse impacts in the small communities along the coastal zones of Alaska and Canada. Also, evaluation of the contribution to global warming and ocean acidification by the release of potential greenhouse gases along the plate boundary will further the understanding of the natural release of these gases and the information can be used to refine the impacts that will occur from climate change, sea level rise, and ocean acidification as it relates to humanity in general.

f. Risks:

The risks that the majority of the goals of this project will not be achieved is very low as the collection of any data within the area of interest will be new and contribute significantly to our primary goal of imaging the seafloor in detail. However, the risk of answering the question of "what role fluids play in the fault movement" is high and will be difficult to answer, as direct evidence of friction along the fault plane will not be obtained from the work we propose. What is important though, is that in comparing recent large magnitude earthquakes along the fault system with the mapped vent sites has the potential to explain how vents, and thus fluids relate to seismology – the first step in trying to answer the question at hand.

Also, like any marine expedition equipment failure and/or sever weather conditions can disrupt data collection increasing the risk of addressing the goals comprehensively. Collection of in situ observations of the seafloor and the collection of substrate and water column samples could be a high risk, but barring sever equipment failure and continuous inclement weather, this risk is also considered low. Therefore, field operation in the area of interest should be done when good weather windows are present, which is from late May until mid-October.

The risk/reward ratio for this project is favorable and appropriate to that desired by SOI. Although some risks exist, the fact that any data collected will be useful and rewarding is a plus and should be viewed as a win-win proposition for all involved.

g. Collaborative efforts

This project is a major collaborative venture with a team of well-recognized and respected marine scientists. This study was initiation through the international organization GeoHab and the Circum-Pacific Council that focuses on mapping the oceans' floor for the purpose of characterizing marine benthic habitats and draws upon geologists, geophysicists, biologists, ecologists, and engineers to advance the science of habitat mapping. Scientists to participate in this proposed project come from many geographic points and disciplines and bring a unique expertise together for the common purpose of advancing knowledge of seafloor processes. Through this team of scientists the results of this study will be leveraged to apply to similar goals elsewhere around the world and a network of expertise will be expanded.

Potential for future collaboration is anticipated in the form of developing partnerships with those organizations from which the participants of the cruise are home based. Continuation of the work along the QC-FW fault system will be undertaken in collaboration with the GSC, USGS, SSSC, and MLML's Center for Habitat Studies and MLML/Sea Doc Society's Tombolo Mapping Lab. In addition, un-defined international studies are anticipated to develop from this work, which most likely will be conceived during the cruise.

h. Project deliverables – see Table 1

Maps:

Bathymetry, Backscatter, Geologic, Geohazards, Habitats, Structural (Tectonics), Other (Maps that may be constructed once data and interpretations are completed).

Tables:

Geophysical line numbers and coordinates, Sample locations, ROV track lines and stations, Fluid and gas samples, Substrate samples, Biological samples. Other (tables that may be constructed once data is collected)

Reports:

Cruise report, Progress reports, Reports on Findings/Results (e.g., fluids, substrate, biology/ecology), Hazards report, Climatology report
Other (reports that may occur once data collection and results have been interpreted

Table 1 Project Deliverables

ID	**Deliverable**	**Responsible Person**	**Dependencies**
Maps A	MBES bathymetry	PIs Greene & Barrie	Processing (GSC)
Maps B	MBES backscatter	PIs	Processing (GSC)
Maps C	Sample Locations	Neelands/Picard	GIS processing
Maps D	Geology	PIs	Interpretations

Maps E	Geohazards	PIs	Interpretations
Maps F	Habitats	PIs	Interpretations
Maps G	Structural	PIs	Interpretations
Tables A	Lines & Coordinates	Neelands/Picard	N/A
Tables B	Sample Locations	Neelands/Picard	N/A
Tables C	ROV Stations	Neelands/Picard	N/A
Tables D	Bilogical Samples	Conway	Taxonomic ID
Tables E	Fluid/gas samples	Greinert/McMurtry	N/A
Tables F	Plume chemistry	Greinert/McMurtry	Lab analyses
Tables G	Substrate samples	Neeland/Picard	Lab analyses
Tables H	Geophysical log	Conrad/USGS Tech.	N/A
Report A	Cruise Report	PIs	Data Processing
Report B	Progress Report	PIs	Interpretations
Report C	Geohazards	PIs	Interpretations
Report D	Fluids/geochemistry	Greinert/McMurtry	Lab analyses
Report E	Tectonics	PIs	Interpretations
Report F	Habitats	PIs	Interpretations

Table 1. Lists of various products that are anticipated to result form the cruise. Additional products may be constructed depending on the data collection results, analyses and interpretations.

i. Results and outcomes – probable publications, presentations

We anticipate writing peer-reviewed papers to be submitted to one or more of the following publications:

EOS, Continental Shelf Research, Marine Geology, Tectonics, Seismological Society of America Bulletin, Geological Society of America Bulletin, European Society of Geophysics, Journal of Sea Research

We anticipate presenting the results of the cruise at the one or more of the following scientific meetings:

AGU, GeoHab, INCISE, Seismological Society of America, Geological Society of America, Geological Association of Canada

j. Outreach program

Opportunities and plans to communicate to broad, global audiences before, during, and after the cruise are vast. First, we will take advantage of the outreach programs and facilities of SSSC to reach the Alaskan populace, those of the GSC to reach the Canadian populace, and the USGS for US exposure. For the State of Washington we will open up a dialog using the SeaDoc web network and for international exposure we will rely upon GRID-Arendal, GEOMAR, Geological Survey of Norway, British Geological Survey and the GeoHab web sites and outreach programs. We will prepare a cruise plan for the global public that will describe the research and set up a means to report to the public in real time during the cruise utilizing SOI's outreach means, if available. We welcome the opportunity to work with a SOI publicity person to obtain as broad of an exposure to our study as possible and in formulating a successful public outreach program using all of the facilities we bring to the project. In addition, we will use the Circum-Pacific Council as an avenue for outreach and as an international organization to facilitate the communications of the results to the Pacific and global scientific communities.

We will contact such science writers as David Perlman of the San Francisco Chronicle and Charles Petit of US News and World Report, acquaintances of the PI and who are reporters that have covered similar types of projects we have undertaken in the past. In addition, we will contact reporters of EOS such as Racial Berkowitz who has reported upon the earlier work we have done in an article titled "Active Mud Volcano Field Discovered off Southeast Alaska" (30 November 2015, *Eos*, 96, doi:10.1029/2015EO040447) and Tom Hesse of the Daily Sitka Sentinel, who published an Alaska Press Club award winning article titled "Sitka Funded Project Discovers Volcano" on the results of our earlier work. We will work with radio and TV commentaries as they have shown considerable interest in our explorations in the past as exemplified in Alaska NPR program by Ed Schoenfeld, Coastal Alaska show "Scientists stumble over active underwater volcano in Southeast" (Juneau, October 2, 2015).

Scientists from the cruise will participate in the Scientists in the School program. *Scientists in the Schools* is a successful program that is delivered by the Sitka Sound Science Center and University of Alaska Southeast with funding from the U.S. Departmet of Agriculture. *Scientists in the Schools* has scientists visit K-12 classrooms in Sitka, Alaska and 9-12 classrooms at Mt. Edgecumbe High School, a state operated boarding school that is 95% Alaska Native. Each scientist visit is preceded by a pre-lesson that is carefully coordinated with the existing science curriculum, helps meet state science standards, exposes students to current research and provides hands on learning opportunities in science disciplines important to Alaska. Scientists lessons help expose students to current research, scientific thinking, problem solving and the breadth of scientific careers and the educational pathways to those careers. Evaluations demonstrate that this program is increasing standardized science test scores (Madden) and improving test scores on My Attitude Toward Science tests for students in Sitka.

There will be opportunities for one or two graduate students to participate in the cruise and to utilize some of the collected data for theses or other reports. In addition, we will also entertain having land-based students learn from processing and interpreting the data we collect. These students will be identified once the project is confirmed to be accepted and will come from the various cruise participants' home institutes as well as from the GeoHab Ron McDowell Student Support pool of students actively involved in the GeoHab network. We are also receptive to having students apply for sailing on our cruise through the SOI web site and program. We anticipate that students will be involved in the collection, processing, and interpretation of the geophysical, geologic and biologic data resulting in them producing written reports that can be incorporated into the overall results reports of the cruise.

4. Data Management Plan

Data management will be a multi-task procedure with a chief data manager aboard ship overseeing the collection, archiving and distribution of the data sets as they accrue. Geophysical data sets including bathymetry, sub-bottom profiles and acoustic water column data will be stored and archived in two places, the GSC, Pacific and USGS, Santa Cruz, CA for replicate safe-keeping (see Appendix II for details). Seafloor samples will be archived at GSC, Pacific and all these data will be handled according to these agencies data management public access protocols. Gas, fluid and biological samples will go to those participants schooled in the discipline to analyze the samples and will be governed by their institute's data management protocols. Public access to all the data will be available through these agencies, and through SOI.

a. Data Generation Activities:

All geophysical data including MBES, seismic-reflection profiles, single channel sonar and water column acoustics will be collected and processed while aboard *Falkor*. DEMs and other map products will be generated on board using ArcGIS and various attributed thematic maps will be constructed. Sub-bottom profiles will be uploaded into the Kingdom Suite™ software for interpretation both onboard ship and on shore once the cruise is completed. ROV video will be reviewed and described while aboard and ROV collected samples will be described and stored for further onshore analyses. Fluid and gas samples will be contained in special vessels for shipment back to land-based laboratories where they will be intensively analyzed.

We anticipate collecting shallow water Kongsberg 710 and deep-water MBES Kongsberg EM 302, single beam Kongsberg EA 600 echo sounder, Simrad EK60 fishery research sounder, high definition omnidirectional fishery 114 kHz sonar, Knudsen CHIRP 3260 12 kHz sub-bottom profiler, USGS mini-sparker high-resolution seismic-reflection profile data from the *Falkor*, and video, still photos, substrate, biologic and fluid samples from aboard the *Falkor* using the 4,500 m diving ROV. Cores and gas samplers will be provided by GEOMAR, and possibly by MBARI, to use from the ROV. We anticipate collecting the geophysical data throughout the cruise during the night and using the ROV in daytime at dive sites determined from interpretations of the geophysical data. We anticipate collecting over 1,500 km of geophysical data, over 50 sediment samples, over 40 fluid samples and at least 20 biological samples, although these numbers may change depending upon our finds. We anticipate serendipitous finds.

b. Roles and Responsibilities:

We will have a chief data manager onboard, Peter Neelands from GSC, Pacific who will be responsible for capturing data, producing metadata, transferring metadata and data to SOI and the participants who are need of the information. He fills this role at GSC and has managed data for past cruises in the area and is familiar with the GSC data management protocols. James Conrad of the USGS will assist and make sure that the

USGS metadata and data management protocols are used as well. Kim Picard will also assist in data management functions.

c. In-Project Data Management:

Data collected aboard the *Falkor* will be collected and bundled into management files on a daily basis and stored on multiple hard drives to facilitate preservation of the data. The hard drives will be secure, pass word protected, and used solely for the transfer and storage of data, not for use in data manipulation. Any data requirements of SOI will need to be communicated and implemented during this activity and the assistance of the identified SOI data manager will be necessary.

d. Metadata and Documentation:

The standard metadata formats used by GSC and USGS will be implemented. Metadata will be supplied along with all the data it represents.

e. Data Quality:

The data manger, Mr. Peter Neelands, along with Ms. Kim Picard will oversee data quality control. Documentation of data archiving and distribution will be logged and available for inquiry.

f. Status of Funding:

No external funding is needed to support the data management for this project as the GSC and USGS will integrate the data into their normal data management scheme. Data that goes to other scientific institutes where it will be analyzed will be incorporated into their normal data management schemes and will not require external funding. Copies of all data that SOI desires to manage will be forwarded to them with the exceptions of samples that are depleted during analyses, but documentation of this activity will be provided to SOI through the data quality and management logs. Data sets and samples that remain after analyses and after the conclusion of the project will remain at the GSC and USGS. Some funds may be identified for radiocarbon dating of selected samples, which we will seek through other external proposals.

g. Dataset Description:

We intend to fill out the SOI Dataset Description Form for each dataset collected.

h. Public Access to Publications and Data:

We intend to make all publications and datasets available to the public for download no later than 12 months after publication of our results. A minimum set of machine-readable metadata elements in a metadata record will be made available free of charge upon initial publication of the results of the cruise. These data will be managed by the GSC and USGS to ensure long-term preservation, as are their normal scientific operating procedures. These procedures will be reported in the final cruise report and the links to be used to obtain the full text of the publications will be provided. SOI will be notified of any publication resulting from the cruise.

5. Logistical requirements:

a. Cruise plan

A total of 24 days of ship time is proposed with 21 at sea days. Two days of mobilization and one day of demobilization time is expected. Once mobilized we would like to sail through the Straits of Juan de Fuca from either Bellingham, WA or Sidney, B.C. (Institute of Ocean Sciences), although Seattle, Victoria or Vancouver, B.C. could be alternative departure ports, and northward along the west coast of Vancouver Island, where we would pass over other reported seeps and test our acoustic systems, to the southern tip of Haida Gwaii (about 1 1/2 days of steaming, see Figure 1), where we would like to start our data collection transit northward up the western side of Haida Gwaii along the QC-FW fault system (Figure 1). We plan on collecting geophysical and water column acoustical data along a transit line from offshore of southern Haida Gwaii (52.01890 – 131.44934) to Northern Haida Gwaii (53.51085 – 133.17370) undertaking geophysical data collection during the night and using the ROV during daylight to sample substrate and water column plumes identified from the geophysical data. This would require about two days of time, after which we plan to arrive at our primary survey site off Dixon Entrance. Coordinates of end points for MBES lines in primary survey area are listed in Table 2 below:

Table 2. Survey Line Coordinates

Line	Longitude	Latitude	Longitude	Latitude
1	-133.62660007500	53.39565308000	-135.37435403600	54.87522754840
2	-133.57673964200	53.41577149190	-135.32355115200	54.89606904390
3	-133.52683234800	53.43586868790	-135.27269576300	54.91688927510
4	-133.47687817100	53.45594462400	-135.22178783300	54.93768819320
5	-133.42687709100	53.47599925520	-135.17082732800	54.95846574800
6	-133.37682908400	53.49603253480	-135.11981421500	54.97922189170
7	-133.32673413200	53.51604441870	-135.06874845900	54.99995657420
8	-133.27659221100	53.53603486000	-135.01763002400	55.02066974660
9	-133.22640330300	53.55600381580	-134.96645888100	55.04136135970
10	-133.17616738700	53.57595123820	-134.91523499500	55.06203136400
11	-133.12588444200	53.59587708320	-134.86395833100	55.08267970990
12	-133.07555444900	53.61578130590	-134.81262885900	55.10330634890
13	-133.41438976200	53.98089878680	-135.01718786700	55.32986641520
14	-133.36375704600	54.00094688720	-134.96565050200	55.35058251130
15	-133.31307590300	54.02097321860	-134.91405933500	55.37127677650
16	-133.26234631300	54.04097773710	-134.86241433300	55.39194916130

Table 2. *Primary survey site line coordinates. Track lines along which bathymetric and geophysical data are to be collected may be altered during the cruise depending on discoveries and weather conditions. Orientation of the lines are based on expected structural alignments but may be changed in trend in order to ride more comfortably through major swell directions and to improve upon the quality of data being collected. All changes will be requested in consultation with the ships' Captain and navigation staff.*

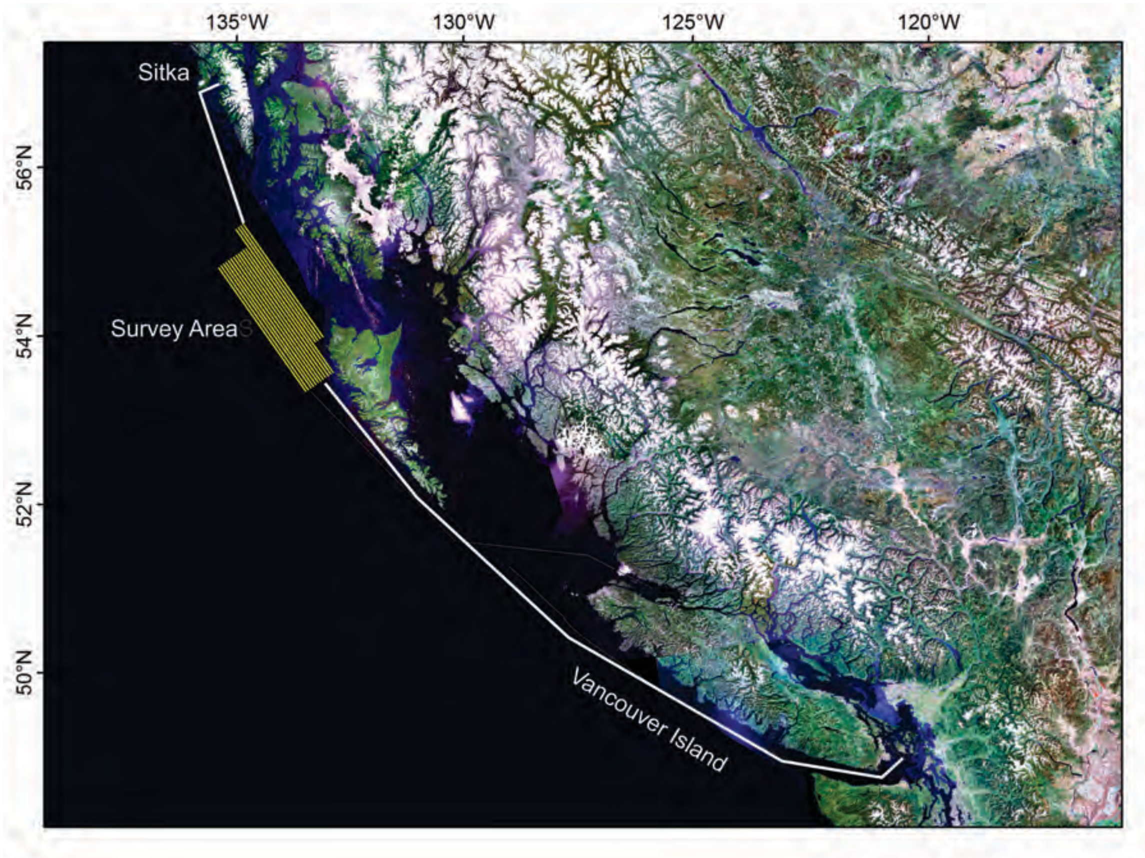

Figure 1. *Map showing generalized transit route from staging area in the Puget Sound, Washington State area to primary survey area off of Dixon Entrance. The route is westward through the Strait of Juan de Fuca and then northward along the western margins of Vancouver Island and Haida Gwaii (former Queen Charlotte Islands). The purpose of this leg is to cross known seep localities and test equipment. Once demarcation port is identified the transit route will be modified to reflect departing route. A short transit leg from the primary survey area to Sitka, Alaska is shown and can be modified once a demobilization port is determined.*

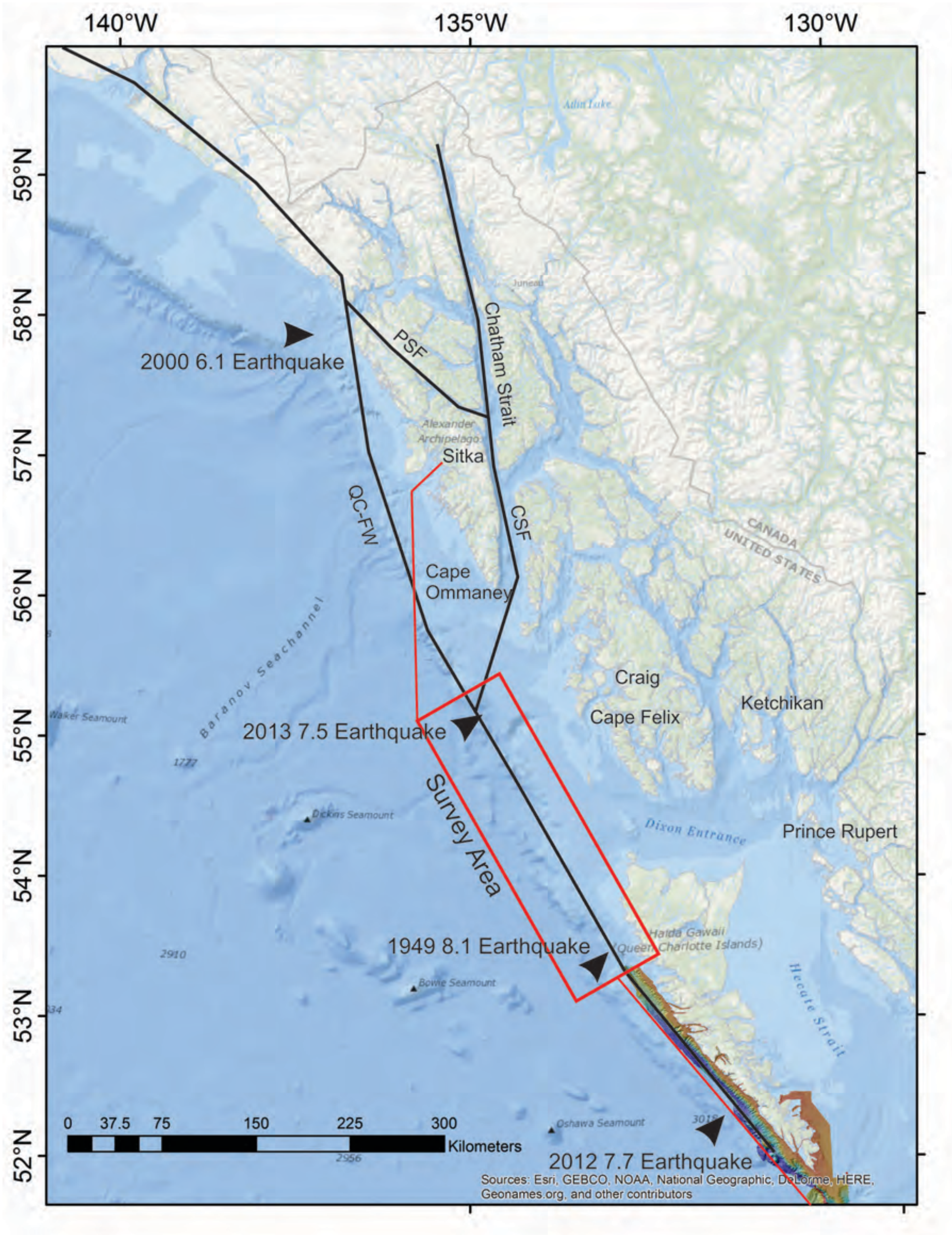

Figure 2. *Map showing western side of Haida Gwaii where a proposed MBES and geophysical lines are to be run. Locations of faults and major earthquakes are also shown.*

At our primary investigation area we plan on initially spending at least two days collecting geophysical data along some of the track lines illustrated in Figure 3 and surveying within the box shown in the figure. Lines 6 to 8 (Table 2) will be run first to determine the structural trend of the seafloor and to obtain data that can be used for the selection of ROV observations and sampling sites. Once our initial survey has been completed we will form an ROV sampling strategy based on the interpretation of the data and then settle into a routine of collecting geophysical data at night and using the ROV for in situ observations and sampling in the daytime. This routine will provide us with the capability to efficiently collect the remotely sensed data and to rapidly, with little transit time, return to targets of interest for sampling. This routine will take place for about 18 days of time. At the completion of our survey in the primary area of interest we will transit to Sitka, Alaska (~1 day transit), our preferred end port where demobilization will take place, although Ketchikan, Alaska or Prince Rupert, B.C. could be alternative demobilization ports.

We are planning for about two weather days when we may have to curtail data collection activities and wait out the weather. When weather impedes the use of the ROV we will continue to collect geophysical data, if possible, and then when the weather improves shift back to using the ROV. This way we can best use the *Falkor* and continue to collect data.

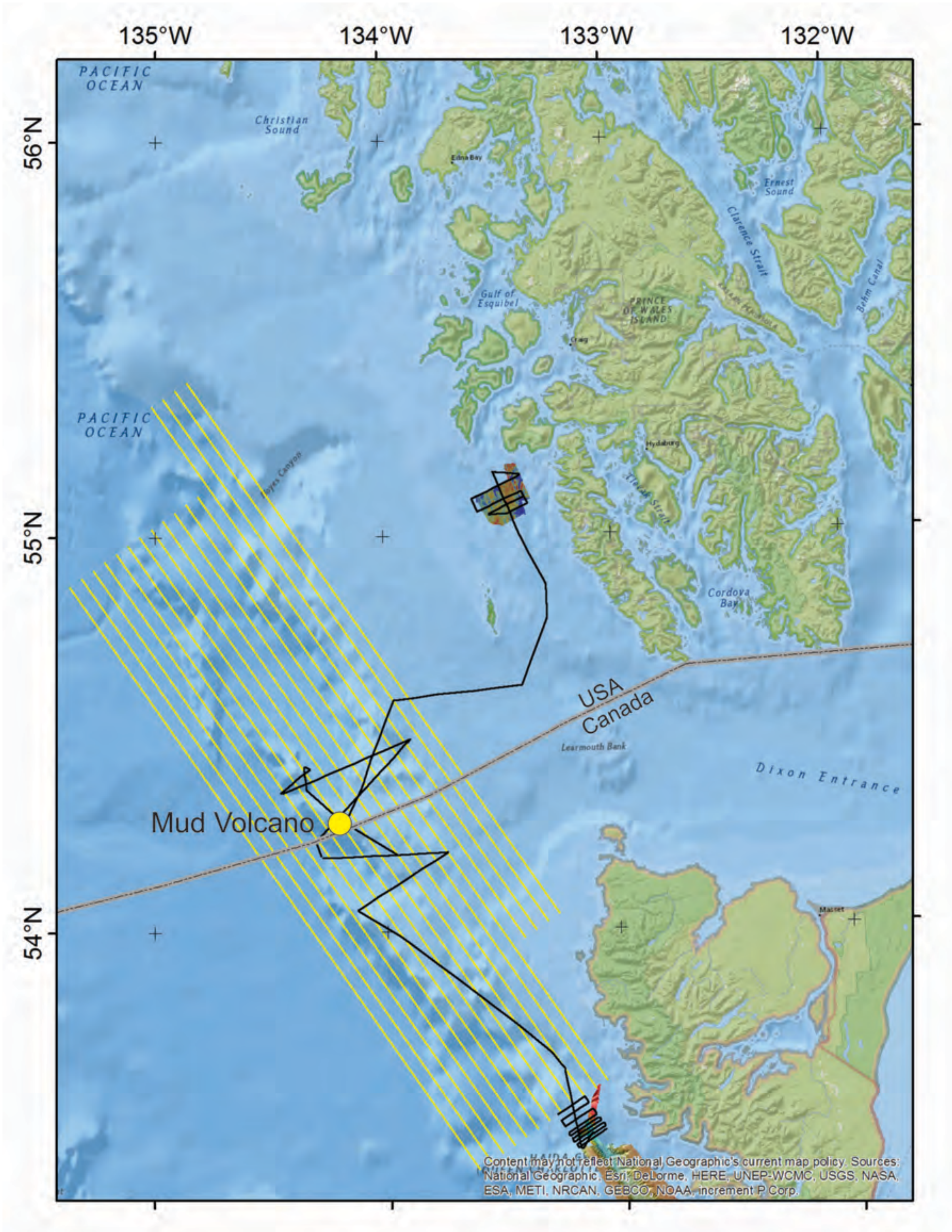

Figure 3. *Map showing MBES and geophysical track lines (yellow) in the primary study site. Black lines represent previously collected geophysical data, gray line represent US-Canada boundary, color patches represent MBES data survey areas.*

b. Name and affiliations of participants
(1) Dr. H. Gary Greene, MLML, Center for Habitat Studies/Tombolo Mapping Lab (PI)
(2) Dr. Vaughn Barrie, GSC, Pacific, Canada (Co-PI)
(3) Dr. Daniel Brothers, US Geological Survey (USGS), Santa Cruz, CA USA (Geophysicist, MBES, seismic)
(4) Dr. Katherine Maier, USGS, Santa Cruz, CA USA (Marine Geologist,)
(5) Mr. James Conrad, USGS, Santa Cruz, CA USA (Geophysicist, seismic)
(6) Dr. Brian Todd, GSC, Atlantic, Canada (Geophysicist, faults)
(7) Dr. Peter Harris, GRID-Arendal, Norway (Marine Geologist, Submarine Canyons)
(8) Dr. Terje Thorsnes, Geological Survey of Norway, Norway (Marine Geologist, habitats)
(9) Dr. Jens Greinert, GEOMAR, Germany (Marine Geochemist, fluids)
(10) Dr. Gary McMurtry, University of Hawaii (Geochemist, mass spectrometer)
(11) Dr. Stewart Nishenko, Padific Gas & Electric Co. (PG&E), San Francisco, CA USA (Seismologist)
(12) Mr. Kim Conway, GSC, Pacific, Canada, (Sedimentologist)
(13) Ms. Kim Picard, Geoscience Australia (Marine Geologist, Data Manager)
(14) Mr. Peter Neelands, GSC, Pacific, Canada (Data Manager, GIS)
(15) Biologist (TBD)
(16) Student (TBD)
(17) Student (TBD)
(18) Technician (TBD, USGS Seismic)

c. On-board staffing requirements:

The science party is listed above under “b”. No Coastal State or marine mammal observers will be necessary for this project. A technician from the USGS will be needed to operate the mini-sparker seismic system, a system that will operate at less than 2 kilojoules of energy.

d. Diplomatic Clearances/Marine Research Authorizations:

Our planned area of study lies within the claimed EEZs of the US and Canada. Clearances will be necessary to operate in these waters by a vessel not from either of these countries. No known marine research authorization is required.

e. Special Permit Requirements:

No special requirements are needed. The area of study is not located in a National Marine Sanctuary or any other known protected area.

f. Dependencies on other projects:

This is a stand-alone project and its success does not depend upon the outcome of any other project. However, previous work by us in the region and future proposed work will nicely supplement the results of this project and the direction to be taken by future projects will depend on the outcome of this proposed work.

g. Project logistics:

The online project logistics forms will be filled out

6. Equipment requirements:

a. Detailed equipment

i. From *Falkor*:

Kongsberg EM 710 MBES echo sounder
Kongsberg EM 302 MBES echo sounder
Single beam Kongsberg EA 600 echo sounder
Simrad EK60 fishery research sounder
High definition omnidirectional fishery 114 kHz sonar
Knudsen CHIRP 3260 12 kHz sub-bottom profiler
4,500 M ROV
Magnetometer (if available)
Gravimeter (if available)
Any gas sensors that may be available.

ii. Supplied by SOI:

Computers for collection and processing *Falko*r data
Bench space
Video recorder and screen to view ROV video and take frame grabs

iii Supplied by Science Party:

Laptop computers and hard drives
Mini-sparker seismic-reflection system
Gas and fluid bottles to hang on ROV
Mass spectrometer to attach and test using the ROV

b. Deck over-the-side handling equipment

With the exception of the ROV, no over-the-side handling equipment is foreseen at this time

c. Some laboratory equipment will be brought onboard by the scientific party but the extent of this is not known at this time.

7. Administration:

This project will be administered by the Sitka Sound Science Center in Sitka, Alaska. The Administrative Contact for the Corresponding Principal Investigator, H. Gary Greene, is Ms. Victoria O'Connell, Research Director, SSSC, 834 Lincoln St. #200, Sitka, AK 99835; phone: (907) 747-8878; E-Mail: voconnell@sitkascience.org. Ms. Brooke Volschenk is the Business Director for SSSC: bvolschenk@sitkascience.org

8. Budget:

a. Instrumentation and equipment needs: With the exception of instruments requested on board the *Falkor* the estimated capital cost for equipment that has been purchased from external funding is approximately $350,000.

b. Salaries, including benefits of the scientific party for preparation, travel, and time on board the *Falkor* (~$357,184) will be paid by the scientists' home institutes and no salary funds are requested from SOI.

c. All instruments belonging to the scientific party will be shipped and expenses paid by the home institutes. Shipment costs for all instruments are approximately $23,000.
d. Total travel costs for all participants to board the ship is approximately $45,900.
e. All participants are covered by insurance from their home institutes and letters supporting this are attached to this proposal.
f. There is no current or external support needed at this time for this project other than some funds to pay for radiometric dating of selected samples.
g. Other support costs including time for interpretation and analyses, student stipends, and workshops is approximately $363,500.

Table 3. Budget

COST TYPE	External Sources	Requested from SOI
Equipment		
A. Seismic system (USGS)	$150,000	$0
B. Bubble Box (GEOMAR)	$ 50,000	$0
C. Gas-Quant-2 system (GEOMAR)	$ 60,000	$0
D. DOMS M 12-1 Mass Spectrometer (UH)	$ 90,000	$0
Staffing		
Total (4) Support & Tech personnel salaries related to cruise preparation	$ 16,125	$0
Total (12) Senior (+PIs) Scientists salaries related to cruise preparation	$103,075	$0
Total (4) Support & Tech personnel salaries for 24 day cruise	$ 24,407	$0
Total (12) Senior Scientists (+PIs) salaries for 24 day cruise	$213,577	$0
Shipping		
A. Seismic system (USGS, Santa Cruz, CA)	$ 3,000	$0
B. Bubble Box (GEOMAR) Kiel, Germany	$ 5,000	$0
C. Gas Quant-2 system (GEOMAR) Kiel, Germany	$ 5,000	$0
D. DOMS Model 12-1 Mass Spectrometer (UH) Honolulu, Hawaii	$ 10,000	$5,000

Insurance

USGS – The U.S. Government (staff & equipment) is self-insured
CGS – Canadian Government (staff & equipment) is self-insured (Appendix III)

GEOMAR – German Government (staff & equipment) self-insured
GSN – Norwegian Government (staff) self-insured
GRID-Arendal – See letter of insurance (Appendix III)
Geoscience Australia – Australian Government (staff) self-insured
UH – University of Hawaii (staff & equipment) insured
PG&E – Company insurance (staff) coverage
PI (Greene) – SSSC and personal insurance ($1 million) coverage
Students & Techs (TBD) – will supply insurance information upon selection

Travel		
Total Cruise Participants' costs	$45,900	$0
Other Required Support		
Shiptime – ~21 days @ sea, ~ 3 days in Port	$ 10,000	TBD by SOI
Analyses & Interpretation of Data 6 investigators for 2 years, part-time	$240,000	$0
Stipends – 2 graduate students (TBD) (to be secured – GeoHab/CPC?)	$ 40,000?	$0
Pre-Cruise Planning Workshop Sidney, B.C. (GSC), Orcas Island, WA (Tombolo Lab), or Santa Cruz, CA (USGS)	$ 28,500	$0
Post-Cruise Results Workshop Sidney, B.C. (GSC), Orcas Island, WA (Tombolo Lab), or Santa Cruz, CA (USGS)	$ 45,000	$0
Subtotals	**$1,139,584**	**$5,000**

Table 4. *Budget calculated from estimates submitted by cruise participants for time and salary, travel costs, and equipment shipping.*

9. Pending Proposals

There are no pending proposals that this project is contingent upon.

10. Current and Pending Research Support

At this time there is a current USGS NERP two-year funded grant for $386,034 that addresses the seismic hazards of the QC-FW fault system and is due to end December 31, 2016. There is a possibility that we will reapply to this organization for additional funds to use in correlating results of this proposal with the results of the NERP proposal and paying for the radiometric dating of samples. In addition, we have requested additional

CCGS Tully time to continue our piston core sampling work during the fall of 2017 and additional multibeam data collection along northeastern Haida Gwaii up to Dixon Entrance in collaboration with the Canadian Hydrographic Service Pacific, using the *CCGS Vector*. No other proposals are being considered at this time.

Support letters for this project by the CGS, USGS, GEOMAR and others can be found in Appendix V.

11. Biographical Information (CVs):

(1) H. Gary Greene

Present Positions

Professor Emeritus, Marine Geology, and Head, Center for Habitat Studies:

San Jose State University, Moss Landing Marine Laboratories (MLML)
8272 Moss Landing Road
Moss Landing, CA 95039-0450
Phone: (831) 771-4141; Fax: (831) 633-7264; Cell (831) 332-3627
E-mail: greene@mlml.calstate.edu

Research Scientist:

Friday Harbor Laboratories, University of Washington
Friday Harbor, San Juan Island, WA
E-Mail: greene3@u.washington.edu

Director:

SeaDoc Society's Tombolo Seafloor Mapping Lab
942 Deer Harbor Road
Eastsound, WA 98245
Phone/fax: 360-376-4993
E-Mail: tombolo@centurytel.net

Professional Preparation

1966 **BSc.**, (Paleontology), California State University, Long Beach
1969 **MSc.**, (Geophysics), California State University, San Jose
1977 **PhD.**, (Marine Geology), Stanford University

Appointments

2006-present	**Professor Emeritus/Researcher**, Moss Landing Marine Labs **Director**, Center for Habitat Studies and Tombolo Mapping Lab
2006-Present	**Research Scientist**, Friday Harbor Labs, University of Washington
2008-Present	**Research Scientist**, SeaDoc Society, Tombolo Mapping Lab, University of California, Davis
1998-2006	**Professor**, Marine Geology, Moss Landing Marine Labs
1998-2008	**Senior Scientist**, Monterey Bay Aquarium Research Institute (MBARI)
1994-1998	**Director**, Moss Landing Marine Labs
1966-1994	**Marine Geologist, Program Manager,** U.S. Geological Survey, (USGS), Menlo Park, CA

Professional Organizations

California Academy of Sciences, **Fellow**
American Geophysical Union (AGU), **Member**
American Association of Petroleum Geologists (AAPG), National and Pacific Section, **Member**
Sigma Xi, **Member**
American Association for the Advancement of Science (AAAS), **Member**
Seismological Society of America (SSA), **Member**
Circum-Pacific Council (CPC), **President**
GeoHab, **Treasurer**

Selected Significant Publications

- (i) **Greene, H.G.**, Murai, L.Y., Watts, P., Maher, N.A., Fisher, M.A., Paull, C.E., and Eichhubl, P., 2005. Submarine landslides in the Santa Barbara Channel as potential tsunami sources. *European Geoscience Union, Natural Hazards and Earth System Sciences*, 0000, 1-27, 2005; SRef-ID 1684-9981/nhess/2005-0000-1.
- (i) **Greene, H.G.**, and Ward, 2003. Mass movement features along the central California margin and mass movements and their consequences: *Kluwer Academic Publishers*, 242-356.
- (i) **Greene, H. G.**, Maher, N. and Paull, C., 2002. Physiography of the Monterey Bay region and implications about continental margin development. *Marine Geology*, 181, 55-82.
- (i) Eichhuble, P., **Greene, H.G.**, and Maher, N., 2002, Physiography of an active transpressive margin basin: high-resolution bathymetry of the Santa Barbara Basin, southern California Continental Borderland: *Marine Geology*, 181, 95-120.
- (i) Eichhubl, P., **Greene, H.G.,** Naehr, T., and Maher, N., 2001, Structural control of fluid flow: Offshore fluid seepage in the Santa Barbara Basin, California: *Jour. Geochemical Exploration*, 69-70.
- (ii) **Greene, H.G.**, O'Connell, V.M. and Brylinsky, C.K., 2011. Tectonic and glacial related seafloor geomorphology as possible demersal shelf rockfish habitat surrogates – examples along the Alaskan convergent transform boundary. *Continental Shelf Research*, 31, 539-553.
- (ii) **Greene, H.G.**, and Barrie, J.V., 2011. Potential Marine Benthic Habitats of the San Juan Archipelago. Geological Survey of Canada Marine Map Series, 4 Quadrants, 12 sheets, scale 1:50,000.
- (ii) **Greene, H.G.**, O'Connell, V.E, Wakefield, W.W., and Brylinsky, C.K., 2007. The offshore Edgecumbe lava field, southeast Alaska: geologic and habitat characterization of a commercial fishing ground: *In* Todd, B. J. and **Greene, H.G.** (eds.), Mapping the Seafloor for Habitat Characterization, *Canadian Geological Association* Special Paper 47, 277-295.
- (ii) **Greene, H.G.**, Bizzarro, J.J., O'Connell, V.M., and Brylinsky, C.K., 2007. Construction of digital potential marine benthic habitat maps using a coded classification scheme and its application: *In* Todd, B.J., and **Greene, H.G.** (eds.), Mapping the Seafloor for Habitat Characterization, *Canadian Geological Association* Special Paper 47, 141-155.
- (ii) **Greene, H.G.**, Yoklavich, M.M., Starr, R., O'Connell, V.M., Wakefield, W.W., Sullivan, D.L. MacRea, J.E. and Cailliet, G.M., 1999. A classification scheme for deep-water seafloor habitats: *Oceanographica ACTA*, 22 (6), 663-678*.*

Synergistic Activities

In cooperation with other geologists and fisheries biologists conceived and developed a marine benthic habitat mapping scheme and GIS attributing code that is now universally used in characterizing and mapping potential seafloor habitats using geophysical and geologic data. Presently mapping upper plate faults above the Cascadia Subduction Zone in the San Juan Archipelago and investigating the seismic hazards of the Queen Charlotte-Fairweather fault system.

Collaborators & Other Affiliations

Collaborators and Co-Editors:

Joe Bizzarro (NOAA, NMFS, Santa Cruz, CA), Bryan Dieter (Center for Habitat Studies, MLML), Mercedes Erdey-Haydon (USGS), Joe Gaydos (SeaDoc Society), Sam Johnson (USGS), Rikk Kvitek (Seafloor Mapping Lab, CSU, Monterey Bay), Holly Lopez (Fugro Pelagos, Inc.), Norman Maher (Tahoe Maps), Robert Pacunski (WDFW), Jennifer Reynolds (UAF), Ed Saade (Fugro Pelagos, Inc.), Bob Stone (NOAA, NMFS, Alaska), Janet Tilden Watts (USGS), Tracy Vallier (Center for Habitat Studies, MLML).

Graduate Advisors and Postdoctoral Sponsors

Professor James Ingle, Stanford University (Emeritus)

Thesis Advisor and Postgraduate-Scholar Sponsors

Luis Camelli (Panama Marine Research Lab), Mercedes Erdey (USGS), Sam Hulmes (University of Hawaii), Holly Lopez (Fugro, Inc.), Patrick Mitts (MBARI) Lee Murai (Biofuels, Inc., San Diego, Janet Tilden Watt (USGS), Steve Watt (USGS).

Advised over 15 Mater of Science students

(2) Dr. J. Vaughn Barrie

(a) Professional Preparation

1970-1974	B.Sc. in Geology, University of Calgary, Canada
1975-1976	Graduate Diploma in Applied Marine Science, University College of Swansea, University of Wales, UK
1976 -1978	M.Sc., Marine Geology and Oceanography, University of Wales, UK
1981-1986	PhD., Oceanography, University of Wales, UK

(b) Appointments

Nov. 1989 – present - Section Head and Research Scientist, Geological Survey of Canada – Pacific, Natural Resources Canada, Institute of Ocean Sciences, Sidney, BC, Canada

Oct. 1990 – present - Adjunct Professor, School of Earth and Ocean Sciences, University of Victoria, Canada

Oct. 1986 - Nov. 1989 - Director, Seabed Group Incorporated, Sidney, British Columbia, Canada

April 1987- Aug. 1987 - Visiting scientist to Scott Polar Research Institute, University of Cambridge, Cambridge, UK

Sept. 1979 - Oct. 1986 - Leader, Seabed Group, Centre for Cold Ocean Resources Engineering (C-CORE), Memorial University of Newfoundland, St. John's, Newfoundland, Canada

Sept. 1974 - Feb. 1979 - Research Associate, Oceanography Department, University College of Swansea (University of Wales), UK

Sept. 1974 – July 1975 - Production Geologist, Sherritt Gordon Mines Ltd., Ruttan Mine, Leaf Rapids, Manitoba, Canada

(c) Publications

Barrie, J.V. and Greene, H.G. (2015) Active Faulting in the northern Strait of Juan de Fuca: Implications for Victoria, British Columbia. Geological Survey of Canada, Current Research 2015-6, 10 p.

Harris, P.T., Barrie, J.V., Conway, K.W. and Greene, H.G. (2014) Hanging canyons of Haida Gwaii, British Columbia, Canada; Fault-control on submarine canyon geomorphology along active continental margins. Deep-Sea Research II, 104, 83-92.

Barrie, J.V., Conway, K.W. and Harris, P.T. (2013) The Queen Charlotte Fault, British Columbia: seafloor anatomy of a transform fault and its influence on sediment processes. Geo-Marine Letters, 33, 311-318.

Duchesne, M.J., Halliday, E.J. and Barrie, J.V. (2011) Using multi-resolution seismic imagery in the time-amplitude and time-frequency domains to determine subsurface fluid migration: A case study from the Queen Charlotte Basin, offshore British Columbia, Journal of Applied Geophysics, 73, 111-120.

Hetherington, R. and Barrie, J.V. (2004) Interaction between local tectonics and glacial unlading on the Pacific margin of Canada. Quaternary International, 120, 65-77.

Barrie, J.V. and Conway, K.W. (2014) Seabed characterization for the development of marine renewable energy on the Pacific margin of Canada. In: Barrie, J.V., Todd, B.J., Heap, A.D., Greene, H.G., Cotterill, C., Stewart, H. and Pearce, B (eds.) Geoscience and Habitat for Marine Renewable Energy, Continental Shelf Research, 83, 45-52.

Barrie, J.V., Todd, B.J., Heap, A.D., Greene, H.G., Cotterill, C., Stewart, H. and Pearce, B. (2014) Editors, Geoscience and habitat mapping for marine renewable energy. Continental Shelf Research, 83, 145 p.

Barrie, J.V., Hetherington, R. and MacLeod, R. (2014) Pacific margin, Canada shelf physiography: a complex history of glaciation, tectonism, oceanography and sea-level change. Chapter 22, In: Chivas, A.R. and Chiocci, F.L. (eds.) Continental Shelves during the last Glacioeustatic Cycle, Geological Society, London, Memoirs, 41, 305-313.

Barrie, J.V. and Conway, K.W. (2013) Paleogeographic reconstruction of Hecate Strait, British Columbia: Changing sea levels and sedimentary processes reshape a glaciated shelf. In: Li, M.Z., Sherwood,

C.R., and Hill, P.R. (eds.), Sediments, Morphology and Sedimentary Processes on Continental Shelves. International Association of Sedimentologists Special Publication, 44, 29-46.
Barrie, J.V., Cook, A. and Conway, K.W. (2011) Cold seeps and benthic habitat on the Pacific margin of Canada. Continental Shelf Research, 31, S85-S92.

(d) Synergistic Activities

- Canadian Director, Circum-Pacific Council for energy and mineral resources, an international non-governmental, non-profit association of earth scientists and engineers that develop and promote research and cooperation among industry, government and academia for the sustainable utilization of earth resources in the Pacific Region (2001-present).
- Principal Investigator of the United State Geological Survey (USGS) Earthquake Hazards Program for External Research Support (NEHRP) entitled 'Investigation of Recent Deformation along the Queen Charlotte-Fairweather Fault System in Canada and Alaska, USA" with the Sitka Sound Science Centre, Alaska.
- Leader of the International Union for Quaternary Research (INQUA) Focus Group on 'Rapid Environmental Changes and Human Activity Impacting Continental Shelf Systems' (2014-2018).
- Invited by the Petroleum and Offshore Division of Geoscience Australia to be a visiting scientist from September 2009 to August 2010.
- Member of the UNESCO response team to assess the impact of the Sumatra tsunamis in the Republic of Seychelles

(e) Collaborators and Other Affiliations

Conway, K, Geological Survey of Canada
Cotterill, C. British Geological Survey
Greene, G, Moss Landing Marine Laboratories
Harris, P., GRID-Arendal, Norway
Heap, A, Geoscience Australia
Hetherington, R, RITM Corp., Canada
Pearce, B, Pelagica Ltd., UK
Todd, B, Geological Survey of Canada
Stewart, H, British Geological Survey

Graduate Students:
Sean Mullan, University of Victoria
Michael Grilliot, University of Victoria
Maeva Gauthier, Coastal and Ocean Resources Inc., Victoria, Canada
Kim Picard, Geoscience Australia

Graduate teaching and supervision of four PhD and eleven M.Sc. students since 1990.

(3) Daniel S. Brothers

Research Geophysicist
US Geological Survey
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Santa Cruz, CA 95060
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AREAS OF EXPERTISE

My expertise is in the fields of Active Tectonics, Seismic Stratigraphy, Subaqueous Paleoseismology and Tectonic Geomorphology. I lead a project aimed understanding earthquake, tsunami and landslide hazards in coastal areas (https://walrus.wr.usgs.gov/geohazards/overview.html).

EDUCATION

2009	Ph.D. in Earth Science Institute for Geophysics and Planetary Physics Scripps Institution of Oceanography University of California, San Diego
2004	B.A. in Geology University of Colorado, Boulder

PROFESSIONAL APPOINTMENTS

10/13 – Present	Research Geophysicist and Marine Geohazards Project Chief, USGS Pacific Coastal and Marine Science Center, Santa Cruz, CA
10/13 – Present	Associate Researcher, Department of Earth and Planetary Sciences, University of California Santa Cruz
10/11 – 09/13	Research Geophysicist, USGS, Woods Hole, MA
12/09 – 10/11	Mendenhall Postdoctoral Fellow, USGS, Woods Hole, MA
09/04 – 11/09	Graduate Research Assistant, Scripps Institution of Oceanography, University of California, San Diego

SELECTED PUBLICATIONS

Brothers, D.S., P. Haeussler, L. Liberty, D. Finlayson, E. Geist, K. Labay, M. Byerly, 2016, A submarine landslide source for the devastating 1964 Chenega tsunami, southern Alaska, *Earth and Planetary Science Letters*, 438, 112–121, doi:10.1016/j.epsl.2016.01.008.

Brothers, D.S., J.E. Conrad, K.L. Maier, C.K. Paull, M. McGann, D.W. Caress, 2015, The Palos Verdes Fault offshore Southern California: Late Pleistocene to present tectonic geomorphology, seascape evolution, and slip rate estimate based on AUV and ROV surveys, *Journal of Geophysical Research: Solid Earth*, 120, 4734–4758, doi:10.1002/2015JB011938.

Brothers, D.S., C. Ruppel, J. Kluesner, J.D. Chaytor, U.S. ten Brink, J.C Hill, C. Flores, B. Andrews, 2013, Evidence for seabed fluid expulsion along the upper slope and outer shelf of the U.S. Atlantic margin, in press, *Geophysical Research Letters*.

Brothers, D.S., K. Luttrell, J. Chaytor, 2013, Sea-level–induced seismicity and submarine landslide occurrence, *Geology*, v. 41, no. 9, 979–982.

Brothers, D.S., U. ten Brink, B. Andrews, 2013, Geomorphic process fingerprints in submarine canyons, v. 338, p.46–63, *Marine Geology*.
Brothers, D.S., U. ten Brink, B. Andrews, J. Chaytor, D. Twichel l , 2013, Geomorphic characterization of the US Atlantic continental margin, v. 337, p.53–66, *Marine Geology*.
Brothers, D.S., A.J. Harding, A. Gonzalez-Fernandez, W.S. Holbrook, G.M. Kent, N.W. Driscoll, J. Fletcher, D. Lizarralde, P.J. Umhoeffer, G. Axen, 2012, Farallon slab detachment and deformation of the Magdalena Shelf, southern Baja California: *Geophysical Research Letters*, doi:10.1029/2011GL050828.
Brothers, D.S., D.K. Kilb, K. Luttrell, G. Kent, G. Lin, N. Driscoll, 2011, Flood induced rupture of faults beneath the Salton Sea: *Nature Geoscience*, 4, 486-492.
Brothers, D.S., N.W. Driscoll, G.M. Kent, A.J. Harding, J.M. Babcock, R.L. Baskin, 2009, Tectonic evolution of the Salton Sea inferred from seismic reflection data: *Nature Geoscience*, 2, 581-584.
Brothers, D.S., G.M. Kent, N.W. Driscoll, S.B. Smith, R. Karlin, J.A. Dingler, A.J. Harding, G.G. Seitz, J.M. Babcock, 2009, New constraints on deformation, slip rate, and timing of the most recent earthquake on the West Tahoe-Dollar Point Fault, Lake Tahoe Basin, California: *Bulletin of the Seismological Society of America*, 99, 2A, 499–519.

SCIENTIFIC COLLABORATORS DURING THE LAST FOUR YEARS

Peter Haeussler (USGS), Jason Chaytor (USGS), Julie Elliot (Purdue), Neal Driscoll (Scripps), Charlie Paull (MBARI), Jenna Hill (CCU), Debbie Hutchinson (USGS), Graham Kent (University of Nevada, Reno), Lee Liberty (Boise State), Karen Luttrell (LSU), Uri ten Brink (USGS).

(4) Katherine L. Maier

Research Geologist

U.S. Geological Survey, Pacific Coastal and Marine Science Center, 2885 Mission St.,
Santa Cruz, CA 95066, kcoble@usgs.gov, 831-460-7461

Professional Preparation

University of Miami	Marine Science & Geology	B.S., 2006
Stanford University	Geological Sciences	Ph.D., 2012

Appointments

2013–*Present* Research Geologist, U.S. Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA
2012–2013 Mendenhall Postdoc Research Geologist, U.S. Geological Survey, Earthquake Science Center, Menlo Park, CA
2009 Research Geologist/Geophysicist Intern, ConocoPhillips, Houston, TX
2008 Exploration Geologist/Geophysicist Intern, ConocoPhillips, Anchorage, Alaska
2007 Research Geologist/Geophysicist Intern, Chevron, San Ramon, CA

Selected Publications

(i) Five most closely related to proposal project

Maier, K.L., Brothers, D.S., Paull, C.K., McGann, M., Caress, D.W., Conrad, J.E. (*submitted*; March 2016). Records of continental slope sediment flow morphodynamic responses to gradient and active faulting from integrated AUV and ROV data, offshore Palos Verdes, southern California Borderland: Marine Geology.

Brothers, D.S., Conrad, J.E., Maier, K.L., Paull, C.K., McGann, M. (2015). The Palos Verdes Fault offshore southern California: Late Pleistocene to Present tectonic geomorphology, seascape evolution and slip-rate estimate based on AUV and ROV surveys. Journal of Geophysical Research – Solid Earth, v. 120, no. 7, p. 4734–4758, doi:10.1002/2015JB011938. IP-063656.

Maier, K.L., Fildani, A., Paull, C.K., Graham, S.A., McHargue, T., and Caress, D.W. (2013). Deep-sea channel evolution and stratigraphic architecture from inception to abandonment from high-resolution Autonomous Underwater Vehicle surveys offshore central California. Sedimentology, v. 60, no. 4, p. 935–960, doi: 10.111/j.1365-3091.2012.01371.x.

Maier, K.L., Fildani, A., McHargue, T., Paull, C.K., Graham, S.A., and Caress, D.W. (2012) Punctuated deep-water channel migration: High-resolution subsurface data from the Lucia Chica channel system, offshore California. Journal of Sedimentary Research, v. 82, p. 1–8, doi: 10.2110/jsr.2012.10.

Maier, K.L., Fildani A., Paull, C.K., Graham, S.A., McHargue, T.R., Caress, D.W., and McGann, M. (2011). The elusive character of discontinuous deep-water channels: Examples from Lucia Chica, offshore California. Geology, v. 39, p. 327–330, doi: 10.1130/G31589.1.

(ii) Five other significant publications

Dartnell, P., Maier, K.L., Erdey, M.D., Dieter, B.E., Golden, N.E., Johnson, S.Y., Hartwell, S.R., Cochrane, G.R., Ritchie, A.C., Finlayson, D.P., Kvitek, R.G., Sliter, R.W., Greene, H.G., Davenport, C., Endris, C., Krigsman, L.M. (2016). California State Waters Map Series—Monterey Canyon and Vicinity, California, U.S. Geological Survey Data Release, 85 p., 10 sheets, scale 1:24,000, http://dx.doi.org/10.5066/F7251G78.

Maier, K.L., Gatti, E., Wan, E., Ponti, D., Pagenkopp, M., Starratt, S., Olson, H., and Tinsley, J. (2015). Quaternary tephrochronology and deposition in the subsurface Sacramento-San Joaquin Delta, California, U.S.A.: Quaternary Research, v. 83, p. 378-393, doi: 10.1016/j.yqres.2014.12.007.

Fildani, A., Hubbard, S.A., Covault, J.A., Maier, K.L., Romans, B.W., Traer, M., and Rowland, J.C. (2013). Erosion at inception of deep-sea channels: Marine and Petroleum Geology, v. 41, p. 48–61, doi: 10.1016/j.marpetgeo.2012.03.006.

Paull, C.K., Ussler, W., Caress, D.W., Lundsten, E., Covault, J.A., Maier, K.L., Xu, J., and Augenstien, S., 2010, Origins of large crescent-shaped bedforms within the axial channel of Monterey Canyon, offshore California: Geosphere, v. 6, p. 1 – 20, doi: 10.1130/GES00527.1.

Caress, D.W., Thomas, H., Kirkwood, W.J., McEwen, R., Henthorn, R., Clague, D.A., Paull, C.K., Paduan, J., and Maier, K.L. (2008). High-resolution multibeam, sidescan, and subbottom surveys using the MBARI AUV *D. Allan B.*, *in* Reynolds, J.R., and Greene, H.G., eds., Marine Habitat Mapping Technology for Alaska, Alaska Sea Grant College Program, University of Alaska, Fairbanks, doi: 10.4027/mhmta.2008.04.

Synergistic Activities

- Several collaborative research cruises along the North American active western margin with USGS and outside institutions (e.g., MBARI, Geological Survey of Canada)
- Journal reviewer and USGS internal reviewer (2012–2016)
- **Student presentation judge, liaison, and Session Chair at AGU conference (2013–2016)**
- USGS Coastal and Marine Program Strategic Planning Writing team member (2014–2015)
- USGS Pacific Coastal and Marine Science Center seminar leader (2014–2015)

Collaborators (*past four years*)

A. Balster-Gee, D.S. Brothers, G.R. Cochrane, S.A. Cochran, J.E. Conrad, P. Dartnell, A. East, M.D. Erdey, J. Ferreira, N.E. Golden, P. Hart, S.R. Hartwell, S.Y. Johnson, J.A. Kluesner, T. Lorenson, M. McGann, K. Rosenberger, H.F. Ryan, R.W. Sliter, A. Tan, M. Torresan, J. Watt; J.D. Chaytor, U. ten Brink; D. Ponti, T. Holzer, K. Knudson, C. Rosa, J. Tinsley; S. Starratt; J.W. Hillhouse, H. Olson, E. Wan, P. Haeussler, R. Witter (USGS); M. Pagenkopp (CA Dept. of Water Resources); C.K. Paull, D.W. Caress, E.M. Lundsten, K. Anderson, R. Gwiazda, H. Thomas, J. Barry (MBARI); W. Symons, E.J. Sumner (Univ. Southampton); M.J.B. Cartigny, M. Clare, J. Gales, P.J. Talling (National Oceanography Centre); D. Parsons, S. Simmons (Univ. Hull); J. Xu (Ocean Univ. China); M.A. Coble, S.A. Graham, G.E. Hilley, M. Malkowski, T. McHargue, L. Shumaker, M. Traer (Stanford Univ.); A. Fildani (Statoil); P.R. King, G.H. Browne, M.J. Arnot, M.P. Crundwell (Geological & Nuclear Sciences); J.V. Barrie, K. Conway, R. Enkin, C. Stacey (Geological Survey of Canada); B.W. Romans (Virginia Tech Univ.); S.A. Hubbard (Univ. Calgary); S. Nishenko (Pacific Gas & Electric Company); S. Arregui, L.A. Barrientos, J.C. Herguera (CISCE); C. Davenport (California Geological Survey); H.G. Greene (Sitka Sound Science Center); C. Endris (Moss Landing Marine Labs); R.G. Kvitek (California State Univ., Monterey Bay); E. Gatti (JPL); J.C. Rowland (Los Alamos National Laboratory); E. Shelef (Univ. of Pittsburgh)

Graduate and Postdoctoral Advisors

Stephan A. Graham, Ph.D. Advisor (2006–2012, Stanford University)
Thomas L. Holzer, Mendenhall Postdoc Supervisor (2012–2013, U.S. Geological Survey)

Thesis Advisor and Postgraduate-Scholar Sponsor

M. Malkowski, USGS Mendenhall Postdoc, co-advisee (2016)
M. Walton, USGS Mendenhall Postdoc, co-advisee (2016)

(5) James Erik Conrad

Geologist
U.S. Geological Survey
Pacific Coastal and Marine Science Center
2885 Mission St.
Santa Cruz, CA 95060
(831) 460-7407
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(a) Professional Preparation

University of California, Berkeley	Earth Science	A.B., 1981
San Jose State University	Geology	M.A., 1993

(b) Appointments

2003-Present, Geologist, USGS Pacific Coastal and Marine Geology
1995-2003, Information Technology Specialist, USGS Pacific Coastal and Marine Geology
1982-1995, Geologist, USGS Branch of Western Mineral Resources

(c) Products

(i) Products most closely related to the proposed project

Brothers, D.S., Conrad, J.E., Maier, K.L., Paull, C.K., McGann, M., and Caress, D.W., 2015, The Palos Verdes Fault offshore Southern California: Late Pleistocene to present tectonic geomorphology, seascape evolution, and slip rate estimate based on AUV and ROV surveys: Journal of Geophysical Research: Solid Earth, v. 120, p. 4734–4758, doi: 10.1002/2015JB011938.

Ryan, H.F., Conrad, J.E., Paull, C.K., and McGann, M., 2012, Slip Rate on the San Diego Trough Fault Zone, Inner California Borderland, and the 1986 Oceanside Earthquake Swarm Revisited: Bulletin of the Seismological Society of America, v. 102, no. 6, p. 2300–2312, doi: 10.1785/0120110317.

Ryan, H.F., Legg, M.R., Conrad, J.E., and Sliter, R.W., 2009, Recent faulting in the Gulf of Santa Catalina; San Diego to Dana Point, *in* Lee, H.J., and Normark, W.R., eds., Earth Science in the Urban Ocean: The Southern California Continental Borderland: Geological Society of America Special Paper 454, p. 291-315, doi: 10.1130/2009.2454(4.5).

Dartnell, P., Conrad, J.E., Ryan, H.F., Finlayson, D.P, 2014, Bathymetry and acoustic backscatter—outer mainland shelf and slope, Gulf of Santa Catalina, southern California: U.S. Geological Survey Open-File Report 1094, 15 p., http://dx.doi.org/10.3133/ofr20141094.

Dartnell, P., Driscoll, N.W., Brothers, D.S., Conrad, J.E., Kluesner, J.A., Kent, G.M., and Andrews, B.D., 2015, Colored shaded relief bathymetry, acoustic backscatter, and selected perspective views of the Inner Borderlands region, southern California: U.S. Geological Survey Scientific Investigations Map 3324, http://dx.doi.org/10.3133/sim3324.

(ii) Other significant products, whether or not related to the proposed project.

Conrad, J.E., Hein, J.R., Chaudhuri, A.K., Patranabis-Deb, S., Mukhopadhyay, J., Deb, G.K., and Buekes, N.J., 2011, Constraints on the development of Proterozoic basins in central India from ^{40}Ar/^{39}Ar analysis of authigenic glauconitic minerals: Geological Society of America Bulletin, v. 123, no. 1/2, p. 158–167.

Cucciniello, C., Conrad, J.E., Grifa, C., Melluso, L., Mercurio, M., Morra, V., Tucker, R.D., Vincent, M., 2010, Petrology and geochemistry of Cretaceous mafic and silicic dykes and spatially associated lavas in central-eastern coastal Madagascar, i*n* Srivastava, R.K., ed., Dyke Swarms: Keys for Geodynamic Interpretation: Springer-Verlag Berlin Heidelberg, Ch. 21, p. 345-375.

Conrad, J.E., and McKee, E.H., 1996, High-precision ^{40}Ar/^{39}Ar ages of rhyolitic host rock and mineralized veins at the Sleeper Deposit, Humboldt, County, Nevada, *in* Coyner, A.R., and Fahey, P.L., eds.,

Geology and Ore Deposits of the American Cordillera: Geological Society of Nevada Symposium Proceedings, Reno/Sparks, Nevada, April 1995, p. 257-262.

McKee, E.H., and Conrad, J.E., 1996, A tale of 10 plutons–Revisted: Age of granitic rocks in the White Mountains, California and Nevada: Geological Society of America Bulletin, v. 108, n. 12, p. 1515-1527.

Conrad, J.E., McKee, E.H., Rytuba, J.J., Nash, J.T., and Utterback, W.C., 1993, Geochronology of the Sleeper deposit, Humboldt County, Nevada: Epithermal gold-silver mineralization following emplacement of a silicic flow-dome complex: Economic Geology, v. 88, no. 2, p. 81-91.

(d) Synergistic Activities

Represented USGS expertise on the Senior Seismic Hazard Assessment Committee (SSHAC) panel evaluating the geologic hazards associated with the San Onofre Nuclear Generating Station (SONGS) in response to a U.S. Nuclear Regulatory Commission Request for Information. Served as Resource Expert in SONGS SSHAC Workshop 1 on January 14-15, 2013, presenting new USGS data collected offshore SONGS. Served as Proponent Expert in SONGS SSHAC Workshop 2 on August 12-14, 2013, presenting interpretation of geology offshore SONGS largely derived from new USGS data, and responded to follow-up inquires from the SSHAC panel developing logic trees for a probabilistic seismic hazard assessment for SONGS.

(e) Collaborators & Other Affiliations

Andrews, Brian D., U.S. Geological Survey; Balster-Gee, Alicia, U.S. Geological Survey; Barrie, J. Vaughn, Geological Survey of Canada; Brothers, Daniel S., U.S. Geological Survey; Caress, David W., Monterey Bay Aquarium Research Institute; Chaytor, Jason D., U.S. Geological Survey; Conrad, Tracey A., U.S. Geological Survey; Conway, Kim W., Geological Survey of Canada; Dartnell, Peter, U.S. Geological Survey; East, Amy E., U.S. Geological Survey; Enkin, Randal J., Geological Survey of Canada; Finlayson, David P., Chesapeake Technology, Inc.; Genetti, Jennifer, U.S. Geological Survey; Greene, H. Gary, Moss Landing Marine Labs; Haeussler, Peter J., U.S. Geological Survey; Hein, James R., U.S. Geological Survey; Kent, Graham M., University of Nevada, Reno; Kluesner, Jared A., U.S. Geological Survey; Maier, Katherine L., U.S. Geological Survey; McGann, Mary, U.S. Geological Survey; Nishenko, Stuart P., Pacific Gas & Electric Company; Paull, Charles K., Monterey Bay Aquarium Research Institute; Ritchie, Andrew C., National Park Service; Ryan, Holly F., U.S. Geological Survey; Simms, Alexander R., University of California, Santa Barbara; Sliter, Ray W., U.S. Geological Survey; Spinardi, Francesca, U.S. Geological Survey; Stacey, Cooper, Geological Survey of Canada; Steel, Elisabeth, University of California, Santa Barbara; Warrick, Jonathan A., U.S. Geological Survey; Watt, Janet T., U.S. Geological Survey; Witter, Robert C., U.S. Geological Survey

(6) Brian J. Todd

Affiliation	Geological Survey of Canada (Atlantic) Natural Resources Canada
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Professional preparation

University of Western Ontario, Honours B.Sc., 1978
Dalhousie University, M.Sc., 1984
Dalhousie University, Ph.D., 1988

Appointments

Research Scientist, Geological Survey of Canada, 1999 to present
Research Scientist, Geological Survey of Canada, 1990 to 1996

Publications

Shaw, J., Todd, B.J., Li, M.Z., Mosher, D.C., and Kostylev, V.E. 2014. Continental shelves of Atlantic Canada. *In*: Chiocci, F.L., Chivas, A.R. (*Eds*), Continental Shelves of the World: Their Evolution During the Last Glacio-Eustatic Cycle, Geological Society, London, Memoirs, 41, 7-19, doi: 10.1144/M41.2

Pickrill, R.A., Todd, B.J., Smith, S.J., Barrie, J.V., and Conway, K.W. 2014. Marine habitat mapping in Canada's oceans. *In*: Nettleship, D.N., Gordon, D.C., Lewis, C.F.M., M.P. Latrémouille, M.P. (*Eds*), Voyage of Discovery: Fifty years of marine research at Canada's Bedford Institute of Oceanography, BIO–Oceans Association, Dartmouth, Nova Scotia, 185–190.

Todd, B.J., Shaw, J., Li, M.Z., Kostylev, V.E., and Wu, Y. 2014. Distribution of subtidal sedimentary bedforms in a macrotidal setting: the Bay of Fundy, Atlantic Canada. Continental Shelf Research. doi: 10.1016/j.csr.2013.11.017.

Shaw, J., Todd, B.J., and Li, M.Z. 2014. Geologic insights from multibeam bathymetry and seascape maps of the Bay of Fundy, Canada. Continental Shelf Research. doi: 10.1016/j.csr.2013.12.015.

Todd, B.J., and Shaw, J. 2012. Laurentide Ice Sheet dynamics in the Bay of Fundy, Canada, revealed through multibeam sonar mapping of glacial landsystems. Quaternary Science Reviews, 58: 83–103. doi: 10.1016/j.quascirev.2012.10.016

Synergistic Activities

- Co-editor of volume, Mapping the Seafloor for Habitat Characterization, Geological Association of Canada, Special Paper 47, 2007
- Co-editor of volume, Submarine Glacial Landforms: Modern, Quaternary and Ancient, Geological Society of London, Memoir 47, 2016
- Ron MacDowell Student Award Committee, GeoHab

Collaborators and Other Affiliations

Batchelor, C.L	University of Cambridge
Barrie, J. Vaughn	Geological Survey of Canada

Bell, Trevor J. University of Newfoundland
Cameron, G.D.M Geological Survey of Canada
Canals, Miquel University of Barcelona
Conway, Kim W. Geological Survey of Canada
Cooper, Allan K. US Geological Survey
Dowdeswell, Julian A. University of Cambridge
Dowdeswell, Evelyn K. University of Cambridge
Greene, H. Gary Sitka Sound Science Center (SSSC), Center for Habitat Studies, Moss Landing Marine Labs (San Jose State University), and Tombolo Mapping Lab, SeaDoc Society (University of California, Davis)
Gyllencreutz, Richard Stockholm University
Hogan, Kelly E. British Antarctic Survey
Jakobsson, Martin Stockholm University
King, Edward L. Geological Survey of Canada
King, Thomas University of Alberta
Kostylev, Vladimir E. Geological Survey of Canada
Lewis, C.F. Michael Geological Survey of Canada
Li, Michael, Z. Geological Survey of Canada
Mayer, Larry A. University of New Hampshire
Mosher, David C. University of New Hampshire
Pickrill, Richard A. Geological Survey of Canada
Piper, David, J.W. Geological Survey of Canada
Reynolds, Jennifer R. University of Alaska
Saint-Ange, Franke Beicip Franlab
Sharp, Martin J. University of Alberta
Shaw, John Geological Survey of Canada
Smith, Stephen J. Fisheries and Oceans Canada
Solheim, Anders Norwegian Geotechnical Institute
Sonnichsen, Gary V. Geological Survey of Canada
Wu, Yongsheng Fisheries and Oceans Ca

(7) Peter T Harris

Managing Director, GRID-Arendal

(a) Professional Preparation

University of Washington, Seattle, USA, B.Sc. 1981
University of Wales, Swansea, U.K., M.Sc., 1982, Ph.D. 1984

(b) Appointments

2014-present: Managing Director, GRID-Arendal, Arendal, Norway, www.grida.no
2003-2014: Group Leader and Senior Marine Science Advisor, Marine & Coastal Environment Group, Geoscience Australia, Canberra, Australia, www.ga.gov.au
1994-2003: Leader of Palaeo-environment Program, Geoscience Australia and Antarctic CRC, Hobart, Tasmania, Australia, www.acecrc.org.au
1986-1994: Research Fellow and Senior Lecturer, Sydney University, Sydney Australia

(c) Publications

Papers relevant to the study area:

1. Harris, P.T., Barrie, J.V., Conway, K.W., Greene, H. Gary, (2014) Hanging canyons of Haida Gwaii, British Columbia, Canada: Fault-control on submarine canyon geomorphology along active continental margins. *Deep Sea Research Part II: Topical Studies in Oceanography* 104, 83-92.
2. Barrie, J.V., Conway, K., Harris, P.T. (2013) The Queen Charlotte Fault, British Columbia: seafloor anatomy of a transform fault and its influence on sediment processes. *Geo-Marine Letters*, 33:311-318.

Papers relevant to the submarine canyons:

3. Harris, P. T. and Whiteway, T. (2011) Global distribution of large submarine canyons: geomorphic differences between active and passive continental margins. *Marine Geology* 285, 69-87.
4. Harris, P.T., MacMillan-Lawler, M., Rupp, J., Baker, E.K., (2014) Geomorphology of the oceans. *Marine Geology* 352, 4-24.
5. Huang, Z., Nichol, S.L., Harris, P.T., Caley, J., 2014. Classification of submarine canyons of the Australian continental margin. *Marine Geology* 357, 362-383.
6. Heap, A., Harris, P.T., 2008. Geomorphology of the Australian margin and adjacent sea floor. *Australian Journal of Earth Science* 55, 555-584.

Other papers related to research mentioned below:

7. Harris, P.T., 2014. Shelf and deep-sea sedimentary environments and physical benthic disturbance regimes: a review and synthesis *Marine Geology* 353, 169–184.
8. Harris, P.T., Heap, A.D., Marshall, J.F., McCulloch, M.T., 2008. A new coral reef province in the Gulf of Carpentaria, Australia: colonisation, growth and submergence during the early Holocene. *Marine Geology* 251, 85-97.
9. Harris, P.T., Whiteway, T., 2009. High Seas Marine Protected Areas: benthic environmental conservation priorities from a GIS analysis of global ocean biophysical data. *Ocean and Coastal Management* 52, 22-38.
10. Harris, P.T., Brancolini, G., Armand, L., Busetti, M., Beaman, R.J., Giorgetti, G., Prestie, M., Trincardi, F., 2001. Continental shelf drift deposit indicates non-steady state Antarctic bottom water production in the Holocene. *Marine Geology* 179, 1-8.

(d) Synergistic Activities

1. I have participated in 32 marine surveys since 1986, mostly in the role of cruise leader or co-leader, including 4 cruises to Antarctica, aboard national (Australian) and international vessels. In these surveys I have planned and supervised the collection of deep sea sediment cores (piston and gravity cores), shallow drilling and vibrocoring, deployment of current meter moorings, CTD water column profiles, camera and video tows, dredging rock samples and various acoustic

surveys (multibem sonar, multichannel and single channel seismics, etc.). These surveys were conducted to support evidence-based decision-making by government in relation to climate change, conservation and marine spatial planning.

2. I have designed research programs in estuarine, shelf and deep sea environments to study palaeoenvironments and depositional systems in relation to physical processes, particularly tidal currents (shelf and estuarine) and density flows. My work on documenting tidal depositional systems includes research on the Fly River delta in Papua New Guinea, which is the type-case for a tidal deltaic system, and is cited in sedimentology textbooks. My work on submarine canyons includes regional and global assessments of their geomorphic attributes in relation to tectonic setting and sediment flux over geologic timescales.
3. Research I have published provides evidence that Antarctic bottom water production through the Holocene is not in a steady-state condition, but that bottom water production sites shift along the Antarctic margin over decade to century timescales as conditions for the existence of polynyas change. My work from Antarctic sediment cores (1994-2000), containing layers of cross-bedded sediments indicating phases of stronger bottom currents, collected on the Mac.Robertson shelf and Adélie Land, shows that they have switched "on" and "off" again as important bottom water production sites over the last several thousand years.
4. I planned a survey campaign in the Gulf of Carpentaria, Australia, that discovered and documented a previously un-recognised coral reef province, living at mesophotic depths and therefore invisible to remotely sensed imagery. This campaign (2004-08) included biological and geological sampling to provide a multidisciplinary understanding of the evolution of these types of coral reefs in the Holocene. Outcomes of this research include the Australian government including the Carpentaria reefs within a national marine protected area network and contributed to global recognition of mesophotic coral reefs as documented in a recent report by the United Nations: http://www.grida.no/publications/mesophotic-coral-ecosystems
5. Applications of biophysical data to classify and characterise benthic habitats and marine environments has been a particular focus of my research. I have lead research work that has employed multivariate statistical techniques to synthesise overlapping spatial data layers to classify habitats and predict regional and local patterns of biodiversity and species distributions.

(e) Collaborators & Other Affiliations

Dag Olav Andersen (University of Agder, Norway); Elaine K. Baker (GRID-Arendal); Vaughn Barrie (NR Canada); Rob Beaman (James Cook University); Thomas Bridge (James Cook University); Brendan Brooke (Geoscience Australia); Silvia Ceramicola (OGS, Italy); Kim Conway (NR Canada); Mark Costello (Univ Auckland, New Zealand); H. Gary Greene (Tombolo Marine Laboratory, USA); Zhi Huang (Geoscience Australia); Jan Atle Knutsen (IMR, Norway); Halvor Knutsen (IMR, Norway); Miles Macmillan-Lawler (GRID-Arendal); Scott Nichol (Geoscience Australia); Phil O'Brien (Geoscience Australia); Roger Sayre (USGS); Jody Webster (University of Sydney); Trevor Ward (University of Technology, Sydney); Dawn Wright (Esri, USA).

(8) Terje Thorsnes

Professional preparation

University of Bergen, B.Sc., 1983
University of Bergen, Cand. Scient., 1985

Appointments

1987 – present: Geological Survey of Norway
June 2007 - present: Senior geologist, 100%
2005 – June 2007: Senior geologist (80%)
2005 – June 2007: Secretary General, Geological Society of Norway (20%)
2005-2005: Leader, IUGS Secretariat
2000-2004: Program manager, Regional data and environment
1995-2003: Team manager, Marine Geology
1993-1994: Senior geologist
1987-1992: Geologist

Publications related to the project:

Cremiere, A., Lepland, A., Chand, S., Sahy, D., Condon, D. J., Noble, S. R., Martma, T., **Thorsnes, T**., Sauer, S., and Brunstad, H., 2016, Timescales of methane seepage on the Norwegian margin following collapse of the Scandinavian Ice Sheet: Nature Communications. DOI: 10.1038/ncomms11509

Crémière, A., Lepland, A., Chand, S., Sahy, D., Kirsimäe, K., Bau, M., Whitehouse, M. J., Noble, S. R., Martma, **T., Thorsnes**, T., and Brunstad, H., 2016, Fluid source and methane-related diagenetic processes recorded in cold seep carbonates from the Alvheim channel, central North Sea: Chemical Geology, v. 432.

Chand, S., **Thorsnes, T**., Rise, L., Brunstad, H., Stoddart, D., Bøe, R., Lågstad, P., and Svolsbru, T., 2012, Multiple episodes of fluid flow in the SW Barents Sea (Loppa High) evidenced by gas flares, pockmarks and gas hydrate accumulation: Earth and Planetary Science Letters, v. 331–332, p. 305-314.

Other publications

Ottesen, D., Stokes, C. R., Bøe, R., Rise, L., Longva, O., **Thorsnes, T**., Olesen, O., Bugge, T., Lepland, A., and Hestvik, O. B., 2016, Landform assemblages and sedimentary processes along the Norwegian Channel Ice Stream: Sedimentary Geology, v. 338, p. 115-137.

Thorsnes, T., Bellec, V., Baeten, N., Plassen, L., Bjarnadottir, L., Ottesen, D., Dolan, M., Elvenes, S., Rise, L., Longva, O., Bøe, R. and Lepland, A.: Mid-Norwegian Shelf and Slope. The Seabed - Marine Landscapes, Geology and Processes, 92-115. *In* Buhl- Mortensen, L., Hodnesdal, H. and **Thorsnes, T**. (eds.): The Norwegian Sea Floor - New Knowledge from MAREANO for Ecosystem-based Management. MAREANO 2015, 192 pp.

Thorsnes, T., Bellec, V., and Dolan, M., 2016, Cold-water coral reefs and glacial landforms from Sula Reef, mid-Norwegian shelf: Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient. Geological Society, London, Memoirs, v. 46, 2 pages, accepted.

Thorsnes, T., Rise, L., Bellec, V., and Chand, S., 2016, Shelf-edge slope failure and reef development: Trænadjupet Slide, mid-Norwegian shelf: Atlas of Submarine Glacial Landforms: Modern, Quaternary and Ancient. Geological Society, London, Memoirs, v. 46, 2 pages, accepted.

Synergistic activities

I have in 2005-2012 coordinated and led the geological part of Norwegian MAREANO seabed programme, which is an integrated program for mapping the bathymetry, geology, biology and chemistry of the Norwegian territories. Since 2012, I have been responsible for the R&D, involving studies with AUVs and multibeam water column data. The program has an annual budget of c. 15 Million US dollars, and is regarded as one of the largest and most successful seabed mapping programmes of its kind. In the programme, I have been active in web dissemination, and dissemination through newspapers and television. I have been a co-editor of two books with results from the projects, and been main responsible for several chapters (see example in the reference list - Other publications.

I have also been the project leader of a cooperation project NGU has with oil company Lundin, where we have been investigating shallow hydrocarbon systems, gas leakages and related features (see publications of Cremiere above). For this project, I have developed a database of gas flares (detected from multibeam water column data) which will be published on the MAREANO web (www.mareano.no), once the results have been published scientifically (a manuscript is under preparation).

Other Affiliations

I am member of the Centre of Excellency CAGE (Centre for Arctic Gas Hydrate, Environment and Climate), University of Tromsø, Norway.

Collaborators
Buhl-Mortensen, L., Institute of Marine Research
Chand, S Geological Survey of Norway
Cremiere, A., Geological Survey of Norway
Hodnesdal, H., Norwegian Hydrographic Service
Lepland, A., Geological Survey of Norway
Lågstad, P., Norwegian Defence Research Institute

(9) Professor Jens Greinert

GEOMAR Helmholtz Centre For Ocean Research, Kiel, Wischhofstrass 1-3, 24148 Kiel, Germany. Email: jgreinert@geomar.de

Professional Education

10. 88 – 02. 95	Geology and palaeontology; Technical University Carolo Wilhelmina, Braunschweig, Germany. Degree: Diplom
04. 95 – 11. 98	PhD studies in marine geology; Christian-Albrechts-Universität, Kiel, Germany, and GEOMAR Research Centre, Kiel, Germany. Degree: Dr.rer. nat. (PhD)

Appointments

09. 14 -	Visiting Professor at Centre for Arctic Gas Hydrates, Environment and Climate – CAGE, Tromsoe University, Norway
01. 13 -	Professor for 'DeepSea Monitoring' at Christian-Albrechts University, Kiel, Germany working at GEOMAR Helmholtz Centre for Ocean Research Kiel, Kiel, Germany
05. 09 –	Guest Professor at Ghent University at the Department of Geology and Soil Sciences, Ghent, Belgium.
10. 08 – 12. 12	Senior Scientist and head of department at the Royal Netherlands Institute for Sea Research (NIOZ), Texel, Netherlands
10. 05 – 10. 08	Marie Curie Outgoing International Fellowship at RCMG, Ghent University, Belgium: Working at GNS Sciences, Lower Hutt, New Zealand and Ghent University, Ghent, Belgium
12. 98 – 06. 05	Post-doctoral fellow at GEOMAR Research Centre, Kiel (Germany), Department of Marine Environmental Geology (Prof.Dr. Erwin Suess)
04. 95 – 11. 98	PhD student at GEOMAR Research Centre: Research on authigenic cold vent precipitates (carbonate and barite) and gas hydrates at the Aleutian and Cascadia Margins (Pacific Ocean)(Prof.Dr. Erwin Suess)

Publications:

(i) Urban, P., Köser, K., and **Greinert, J.** Acoustic mapping of shallow water marine bubble streams using multibeam water column data. Limnol. Oceanogr.: Methods (conditional acceptance, summer 2016).

(i) Veloso, M., **Greinert,. J.**, Mienert, J., and De Batits, M. (2015): A new methodology for quantifying bubble flow rates in deep water using splitbeam echosounders: Examples from the Arctic offshore NW-Svalbard. Limnol. Oceanogr.: Methods, doi: 10.1002/lom3.10024

(i) Smith, J.A.,Mienert. J., Bünz, S., and **Greinert, J.** (2014): Thermogenic methane injection via bubble transport into the upperArctic Ocean from the hydrate-charged Vestnesa Ridge, Svalbard. Geochemistry, Geophysics, Geosystems. DOI 10.1002/2013GC005179

(i) Schneider von Deimling, J., Rehder, G., **Greinert, J.**, McGinnnis, D.F., Boetius, A., Linke, P. (2011): Quantification of seep-related methane gas emissions at Tommeliten, North Sea. Continental Shelf Research, 31, 867–878.

(i) **Greinert, J.**, McGinnis, D.F., Naudts, L., Linke, P., and De Batist, M. (2010): Atmospheric methane flux from bubbling seeps: Spatially extrapolated quantification from a Black Sea shelf area. Journal of Geophysical Research – Oceans, doi:10.1029/2009JC005381

(ii) **Greinert,J.**, Artemov, Y., Egorov, V., De Batist, M., and McGinnis, D. (2006): 1300-m-high rising bubbles from mud volcanoes at 2080m in the Black Sea: Hydroacoustic characteristics and temporal variability. Earth and Planetary Science Letters, 244, 1-15

(ii) McGinnis, D.F., **Greinert, J.**, Artemov, Y., Beaubien, S.E., and Wüest, A. (2006): The fate of rising methane bubbles in stratified waters: What fraction reaches the atmosphere? Journal of Geophysical Research, 111, C09007, doi:10.1029/2005JC003183.

(ii) Naudts, L., **Greinert, J.**, Artemov, Y., Staelens, P., Poort, J., Van Rensbergen, P., and De Batist, M. (2006): Geological and morphological setting of 2778 methane seeps in the Dnepr paleo-delta, northwestern Black Sea. Marine Geology, 226, 177-199.

(ii) Paull, C., William Ussler III, W., Peltzer, E.T., Brewer, P.G., Keaten, R., Mitts, P.J., Nealon, J.W., **Greinert, J.**, Herguera, J.-C., Perez, M. E. (2007): Authigenic carbon entombed in methane-soaked

sediments from the northeastern transform margin of the Guaymas Basin, Gulf of California. Deep-Sea Research II, 54, 1240–1267

(ii) Suess, E., Torres, M.E., Bohrmann, G., Collier, R.W., **Greinert, J.**, Linke, P., Rehder, G., Trehu, A., Wallmann, K., Winckler, G., and Zuleger E. (1999): Gas hydrate destabilization: Enhanced dewatering, benthic material turnover and large methane plumes at the Cascadia convergent margin. Earth and Planetary Science Letters, 170, 1-15

Synergistic Activities

Within my group we develop technologies for underwater detection and quantification of bubble gas fluxes (1), which will be an essential part of the project. Further we are actively developing AUV based camera systems (2) and stereographic camera – hydroacoustic system for a better 3D reconstruction of the seafloor (used during RV FALKOR 160320).

(1): Veloso, M., **Greinert,. J.**, Mienert, J., and De Batits, M. (2015): A new methodology for quantifying bubble flow rates in deep water using splitbeam echosounders: Examples from the Arctic offshore NW-Svalbard. Limnol. Oceanogr.: Methods, doi: 10.1002/lom3.10024

(2): Kwasnitschka, T., Köser, K., Sticklus, J., Rothenbeck, M., Weiß, T., Wenzlaff, E., Schoening, T., Triebe, L., Steinführer, A., Devey C., and **Greinert, J.** (2016) DeepSurveyCam – A deep ocean optical survey system. *Sensors* 2015, *15*, 1-x manuscripts; doi:10.3390/s150x0000x

From 2009 to 2013 I coordinated the EU funded COST Action ES0902 PERGAMON which brought together atmospheric, permafrost, cryosphere, marine and climate scientist from 14 European countries as well as Russia, USA and Canada (3).

(3): Rachael H. J., Bousquet, P., Bussmann, I., Haeckel, M., Kipfer, R., Leifer, I., Niemann, H., Ostrovsky, I., Piskozub, J., Rehder, G., Treude, T., Vielstädte,, L., and **Greiner, J.** (2016): Effects of climate change on methane emissions from seafloor sediments in the Arctic Ocean: A review. Limnol. Oceanogr. 00, 2016, 00–00; doi: 10.1002/lno.10307

Collaborators and Co-Editors

Althaus, Behrens, Berndt, Berndt, Bialas, Biastoch, Bohlen, Böning, Bussmann, Camphuysen, Coffin, Crutchley, deVries, Devey, Ferre, Friedman, Garcia, Glover, Graves, Haeckel, James, Jones, Jordt, Kaeli, Klaeschen, Köser, Krastel, Kuhnz, Lehmann, Lindsay, Mienert, Morris, Nattkemper, Noffke, Osterloff, Papenberg, Rothenbeck, Ruhl, Ryabenko, Sapart, Scheinert, Schoening, Schoening, Siems, Sikaroodi, Simons, Singh, Snellen, Sommer, Sommer, Steinführer, Sticklus, Stolpovsky, Tran, Treude, Treude, Triebe, vanderBolt, Wallmann, Weiss, Wenzlaff, Aarts, Alevizos, Bett, Brasseur, Bünz, Dale, DeBatits, Durden, Gillevet, Hamdan, Hoekendijk, Koch, Kwasnitschka, Mienert, Niemann, Pfannkuche, Smith, Steinle, Stout, v.Haren, Veloso

Graduate Advisors and Postdoctoral Sponsors

Prof. Dr. E. Suess (retired, affiliated with OSU, Oregon, USA); PhD supervisor Prof. Dr. Gerhard Bohrmann (Bremen University, Germany); PhD supervisor & PostDoc Prof. Dr. Marc De Batits (Ghent Univeristy, Ghent, Belgium); Marie Curie supervisor Dr. Inog Pecher (GNS Science, Lower Hutt, New Zealand), Marie Curie supervisor

Thesis Advisor and Postgraduate-Scholar Sponsor

Anuschka Boender, Royal NIOZ, Netherlands; Dimitrios Eleftherakis, French research Institute for Exploitation of the Sea (IFREMER), France; Lieven Naudts, Operational Directorate Natural Environment – Royal Belgian Institute of NaturalSciences (RBINS): Catarina Leote Centro Ciência Viva de Lagos, Portugal; Colin McGovern Fugro Survey Pty Ltd, Australia; Kristina Pascher, GNS Science, New Zealand, Pär Jansson, Tromsoe University, Norway; Timm Schoening, GEOMAR, Germany; Anne Peukert, GEOMAR, Germany; Cuiling Xu, GEOMAR, Germany; Peter Urban, GEOMAR, Germany, Evangelos Alevizos, GEOMAR, Germany; Maryna Kudzinava, GEOMAR, Germany

The total number of graduate students advised and postdoctoral scholars sponsored: 17

(10) Gary McMurtry

CURRICULUM VITAE

Gary M. McMurtry

Position: Associate Professor
Department of Oceanography
School of Ocean and Earth Science and Technology
University of Hawaii at Manoa
Honolulu, Hawaii 96822

Phone: (808) 956-6858;
Fax: (808) 956-9225;
E-Mail: garym@soest.hawaii.edu
URL: http://www.soest.hawaii.edu/oceanography

Citizenship: USA

Education: B.S., Geological Sciences, University of California, Riverside, 1972
M.S., Geology and Geophysics, University of Hawaii, 1975
Ph.D., Geology and Geophysics, University of Hawaii, 1979

Professional Experience:

1988-Present Associate Professor, Department of Oceanography, University of Hawaii, Honolulu, Hawaii.

1986-1988 Associate Geochemist, Marine Geochemistry Division, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii.

1983-1988 Science Program Director, National Undersea Research Program at the University of Hawaii, Hawaii Undersea Research Laboratory.

1980-1986 Assistant Geochemist, Marine Geochemistry Division, Hawaii Institute of Geophysics, University of Hawaii, Honolulu, Hawaii.

1979-1980 Post-doctoral Research Geologist, Geological Research Division, Scripps Institution of Oceanography, University of California, San Diego, California.

Major Field and Sea Experience:

Co-chief scientist or invited scientist on 24 oceanographic expeditions, including 17 submersible diving campaigns with HURL *Makalii*, *Pisces V*, UNOLS *Alvin*, and IFREMER *Cyana* and *Nautile*. Research areas include: Costa Rica Margin, Loihi Seamount, Cross Seamount, Nuuanu & Wailau giant submarine landslides, Hawaii; Northern Papua New Guinea; South Central Pacific seamounts and back-arc spreading centers; Tahiti (Teahitia), Pitcairn (Bounty) & Austral (Macdonald) hotspot seamounts; Northern Mariana Arc seamounts; Gorda-Juan de Fuca Ridges; Hawaiian Archipelago seamounts; North Fiji Basin; and Enewetak Atoll, 1981-2005.

Conducted USDOE magmatic gas research on Ruapehu Volcano, New Zealand; Sierra Negra & Alcedo Volcanoes, Galapagos; Mount St. Helens Volcano, Washington; Iwodake Volcano, Satsuma Iwojima, Japan; Galeras Volcano, Colombia; Pacaya Volcano, Guatemala; Kilauea Volcano, Hawaii, 1990-1996.
Conducted magmatic gas research on Mt. Erebus Volcano, Ross Island, NSF U.S. Antarctic Research Program, 1978-79.
Conducted geochemical & geophysical exploration on Island of Hawaii, NSF & USDOE Hawaii Geothermal Project, 1973-1978.

Research Interests:

Geochemistry of hydrothermal systems and magmatic volatiles; Marine radiochemistry and absolute age determination; Marine sediments and authigenic minerals, Marine technology and *in situ* instrument development.

(11) Stuart Nishenko

Present Positions

Principal Seismologist

Geosciences Department
Pacific Gas and Electric Company
245 Market Street, Mail Code N4C
San Francisco, CA 94105
Phone: (415) 973-1213; Cell (415) 816-0005
E-mail: spn3@pge.com

Professional Preparation

1975 **BSc** (Geology, *magna cum laude*), City College, New York
1978 **MA** (Geophysics), Columbia University, New York
1983 **PhD** (Geophysics), Columbia University, New York

Appointments

2015-present **Principal Seismologist**, Pacific Gas and Electric Company, San Francisco
2001-2014 **Senior Seismologist**, Pacific Gas and Electric Company, San Francisco
1996-2001 **Earthquake Policy Advisor**, Federal Emergency Management Agency, Washington, DC
1985-1995 **Research Scientist,** US Geological Survey, Golden CO
1983-1985 **National Research Council Postdoctoral Associate**, US Geological Survey, Golden CO

Professional Organizations

American Geophysical Union (AGU), **Member**
Seismological Society of America (SSA), **Member**
Sigma Xi, **Member**

Selected Significant Publications

Greene, H. G., Barrie, J. V., **Nishenko, S**., Conway, K., Enkin, R., Conrad, J., Maier, K. L., Stacey, C., 2016, Determining slip along the Queen Charlotte-Fairweather Fault Zone, *Seismological Res. Lett*., **87**, 2B,

Nishenko, S., Greene, H. G., Hogan, P., and Bergkamp, B., 2016, Paleoseismology of the Shoreline and Oceano Fault Zones, San Luis Obispo Bay, California, *Bull. Seism. Soc. Am*., (submitted)

Nishenko, S., Greene, H. G., O'Connell, D. R. H., Hogan, P., Unruh, J., AbramsonWard, H., McLaren, M. K., 2015, Central Coastal California Seismic Imaging Project: An overview, *Seismological Res. Lett*., **86**, 2B,

Nishenko, S. P., and Jacob, K. H., 1990, Seismic potential of the Queen Charlotte- Alaska-Aleutian Seismic Zone, *Jour. Geophys. Res*., **95**, 2511-2532

Synergistic Activities

Technical Director, Central Coastal California Seismic Imaging Project – coordinated the acquisition, processing, and interpretation of high-resolution 3-D seismic reflection imaging of onshore and offshore areas in the vicinity of the Diablo Canyon Power Plant, California.

Project Manager, PG&E Tsunami Hazard Assessment – coordinated data collection and interpretation of marine geophysical and hydrodynamic tsunami data for evaluation of far-field and local (including submarine mass failure generated) tsunamis at PG&E Humboldt Bay and Diablo Canyon Power Plants.

Liaison from National Research Council Committee on Seismology and Geodynamics to the NRC Committee on National Earthquake Resilience – Research, Implementation and Outreach. Developed a roadmap of national needs in research, knowledge transfer, implementation and outreach to make the United States more earthquake resilient.

Currently *Project Manager* for the PG&E Central Coast Ocean Bottom Seismometer (OBS) Array in addition to investigating the seismic hazards of the Queen Charlotte-Fairweather fault system.

Collaborators & Other Affiliations

Vaughn Barry (GSC)
Neal Driscoll (UC San Diego)
Stephan Graham (Stanford)
Gary Greene (SSSC)
Stephan Grilli (URI)
Phil Hogan (Fugro)
Sam Johnson (USGS)
Graham Kent (UNR)
Rikk Kvitek (Seafloor Mapping Lab, CSU, Monterey Bay)
Thorne Lay (UC Santa Cruz)
Janet Tilden Watt (USGS)

Graduate Advisors and Postdoctoral Sponsors
Professor Lynn Sykes, Columbia University (Emeritus)
James Dewey, US Geological Survey

Thesis Advisor and Postgraduate-Scholar Sponsors

(12) Mr. Kim F.W. Conway

(f) Professional Preparation

1977-1981 B.Sc. in Biology/Geology, University of Victoria, Canada

(g) Appointments

Oct. 1993 – present – Marine Geologist, Geological Survey of Canada – Pacific, Natural Resources Canada, Institute of Ocean Sciences, Sidney, BC, Canada

May 1990 – Oct. 1993- Proprietor, Geomartec Services Incorporated, Sidney, British Columbia, Canada

May 1982 – June 1990 – Marine geoscience seagoing/laboratory technical specialist, Energy, Mines and Resources Canada

(h) Publications

Conway, K.W. and Barrie, J.V. (2015) Large submarine slope failures and associated Quaternary faults in Douglas Channel, British Columbia: Geological Survey of Canada, Current Research 2015-9, 12p.

Conway, K.W., Kung R.B., Barrie. J.V., Hill, P.R., Lintern, D.G. (2013): A preliminary assessment of the occurrence of submarine slope failures in Coastal British Columbia by analysis of swath multibeam bathymetric data collected 2001-2011: Geological Survey of Canada, Open File 7348. Doi:10.4095/292370

Conway, K.W., J.V Barrie, Picard, K and Bornhold, B.D. (2012): Submarine channel evolution: active channels in fjords, British Columbia, Canada, Geo-Marine Letters, v. 32, no. 12, p.301-312.

Conway, K.W. Barrie, J.V. and Krautter M (2005): Geomorphology of unique reefs on the western Canadian shelf: sponge reefs mapped by multibeam bathymetry. Geo-Marine Letters, v. 25, p. 205-213.

Barrie, J.V., Conway, K.W. and Harris, P.T. (2013) The Queen Charlotte Fault, British Columbia: seafloor anatomy of a transform fault and its influence on sediment processes. Geo-Marine Letters, 33, 311-318.

Barrie, J.V., Cook, A. and Conway, K.W. (2011) Cold seeps and benthic habitat on the Pacific margin of Canada. Continental Shelf Research, 31, S85-S92.

Harris, P.T., Barrie, J.V., Conway, K.W. and Greene, H.G. (2014) Hanging canyons of Haida Gwaii, British Columbia, Canada; Fault-control on submarine canyon geomorphology along active continental margins. Deep-Sea Research II, 104, 83-92.

Reidel, M. and Conway K.W. (2015) Paleoseismicity derived from piston coring methods. Explorer and Juan de Fuca Plate systems, British Columbia; Geological Survey of Canada, Current Research 2015-10, 11p.

Thomson, R., Fine, I., Krassovski, M., Cherniawsky, J., Conway, K.W. and Wills, P. (2012):Numerical simulation of tsunamis generated by submarine slope failures in Doulas Channel, British Columbia. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/115. 38 p.

(i) Synergistic Activities

- Leader Glass Sponge Reef Research and Outreach (2005-present).
- Chair – Marine Geosciences Division – Geological Association of Canada (2005-2012)
- Project Leader: Geoscience For Ocean Management: Project Leader for a project examining marine geohazards in the Georgia Basin (2002-2008).

(j) Collaborators and Other Affiliations

Barrie, V., Geological Survey of Canada
Greene, G, Moss Landing Marine Laboratories
Leys, S., University of Alberta, Biology
Stone, R. NOAA Auke Bay Laboratory
Whitney. F., Department of Fisheries and Oceans

(13) Kim Picard

Professional preparation

Université du Québec à Rimouski (Canada), B.Sc. Biology with marine science specialization, 2001
University of Victoria (Canada), M.Sc. Earth and Ocean Science, Marine Geology, 2012

Professional preparation

Aug. 2012-	**Geoscience Australia** Canberra, Australian Capital Territory, Australia Marine Geoscientist, focus on seabed and shallow sub-seabed mapping
2002- 2012	**Geological Survey of Canada, Natural Resources Canada** Sidney, British Columbia, Canada Marine Geoscientist, focus on seabed and shallow sub-seabed mapping
2009- 2010	**Geological Survey of Norway (NGU)** Trondheim, Norway Research scientist
April 2006	**Chesapeake Technology Inc.** Mountain View, USA Sidescan mapping expert
June 2005	**Terra Remote Survey** Sidney, British Columbia, Canada Sidescan mapping expert
Feb.-June 2002	**Canadian Hydrographic Service, Department of Fisheries and Oceans** Rimouski, Quebec, Canada Multibeam sonar data processor
Autumn 2001	**Geological Survey of Canada, Natural Resources Canada** Sidney, British Columbia, Canada Marine Geoscientist
Summer 2001	**Geological Survey of Canada, Natural Resources Canada** Sidney, British Columbia, Canada ***Natural Science Engineering Research Council (NSERC) scholarship recipient in oceanography***
Summer 2000	**Department of Fisheries and Oceans** Rimouski, Quebec, Canada Natural Science Engineering Research Council (NSERC) scholarship recipient in marine biology

Publications

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(3) Barrie, J. V., Hill, P. R., Conway, K. W., **Picard**, **K**., Greene, H. G., 2012. Inland Tidal Sea of the Northeastern Pacific. *In* Seafloor geomorphology as benthic habitat, *edited by* P. T. Harris and E. K. Baker, Elsevier, London, pp. 623-635

(4) Barrie, J V, Hill, P R, Conway, K W, Iwanowska, K**, Picard**, **K**., 2005. Georgia Basin, seabed features and marine geohazards, Geoscience Canada, vol. 32, no. 4, p. 145-156

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(6) Boe, R., Bellec, V., Thorsnes, T., **Picard, K**., Dolan, M., and Rise, L., 2014. Tromsoflaket og Eggakanten. *In* The Norwegian Seafloor, Edited by L. Buhl-Mortensen, L, Hodnesdal, H., Thorsnes, T., Norway: Skipnes kommunikasjon, pp. 22-42

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Synergistic Activities

Development of a collaborative marine acoustic expert network in Australia. This network brings together gouvernemental agencies and universities to share knowledge and expertise in the field of marine acoustic.

Contribution in the search of the Malaysian Airline flight MH370. Development and contribution towards improving the capabilities of deep-sea mapping for the search.

Director of Circum-Pacific Council, an international, non-governmental, tax-exempt association of earth scientists, engineers, and oceanographers, who represent government, industry, academia, and other organizations and institutes with interests primarily in the Pacific region.

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Response:

SCHMIDT OCEAN INSTITUTE

Proposal Title	Tectonic Mischief Along A Transform Margin
Principal Investigator	Dr. H. Gary Greene

Panel Summary:
The panel concurs that the Queen Charlotte - Fairweather fault zone is a major submarine, seismically-active, plate bounding transform fault akin to the San Andreas on land, yet it is poorly mapped and understood relative to all other major fault systems on the North American margin. The proposal was seen as addressing an important and useful problem in mapping the fault in detail to address the degree to which it is a single-fault boundary in this region. While fault-focused fluid expulsion is an important observation to document, the panel remained unconvinced that the central question on whether fluids in the fault zone control fault motion or localize it on a single trace can be answered by the proposed study. It's unclear how the work would actually address friction along the fault. The proposal is innovative in the integration of diverse approaches - from detailed multibeam and sparker seismic mapping to the quantification of gas bubble fluxes and other ROV-borne tools. The fact that recent major earthquakes have likely affected part of the study area while other parts remain unruptured would present a very interesting comparative study but this aspect was not developed in the proposal. Overall, the proposal was seen as having a very worthwhile target for study but was also seen as somewhat unfocused: trying to perhaps do too much all at once instead of focusing on one tractable aspect. The outreach plans were a highlight and seen as diverse and very good, while data sharing plans were found to be wanting. The summary overall rating is Good to Very Good.

Criteria for evaluation
Opportunities to demonstrate innovation in marine scientific operations and practices:
Proposed marine operations are all methods that have been used and are standard or becoming so, but the proposal is very ambitious in fostering advances in the tight integration of a wide variety of geophysical and water column tools and resulting datasets. The team is diverse and very experienced. For Falkor, use of the mini-sparker would be a new application. The ROV-deployed mass spectrometer, Bubble Box system, and other proposed tools represent innovation in Falkor research and extension of the ROV capabilities and experience.

Opportunities for the advancement of ocean research technologies, practices, and methods:
The panel appreciates that the proposed project would take full advantage of all the disparate acoustic imaging tools mounted on Falkor and even add new ones, as well as extending the toolkit of the ROV with new instruments. While perhaps

not advancing ocean research technologies or methods in an absolute sense, the integration of these tools on Falkor would represent a real advance. We would characterize the strength of this project as greater in terms of exploration of unknown areas, and less in terms of new technology development, but do not see that as an overall drawback.

Evidence that the proposed research incorporates significant intrinsic scientific metric and impact potential:
The PI team is very experienced in seafloor imaging and interpretation of tectonic features, as well as cold seep detection and observation, and it shows in the scientific plan. The scientific merit of detailed mapping of a seismically active plate boundary fault, and evaluation of the degree to which relative plate motion is or is not localized, is clear. Detecting and (partially) quantifying fluid venting from the fault zone also has evident merit and impact potential, but it is not clear that the proposed observations could directly address a number of the specific hypotheses. Vent community observations and sampling are proposed, but the team does not appear to have much depth in biology, and it's not clear that these objectives would be realized. Overall, the proposal was rated Good to Very Good in this criterion.

Quality of the data sharing plan:
While the data management plan is detailed and commendable, the data sharing plan is seen as inadequate to the open-sharing ideals of SOI. Most datasets are promised to be made publicly available "12 months after publication of results" with only metadata release earlier - this is in keeping with some governmental funding agency policies, but is not up to SOI standards. In this area, the proposal was scored relatively poorly (ranging from Poor to Good).

Quality of the proposed outreach plan:
The multifaceted outreach plan was seen as a real strength of this proposal, incorporating outreach in Alaska schools with underrepresented populations. The PI team has a great track record of communication with the popular science press and that would be complementary to the school and enrichment program outreach that is proposed.

Justification of Request to NOAA for Rainier Ship Time to Collect MBES Data in Dixon Entrance (Requested in May 2016)

Rationale to Undertake Further Investigation of the Dixon Entrance Venting Field, South East Alaska-Northern BC, Canada

Scientists of a recent US-Canada cooperative cruise, which was organized to investigate the potential seismic hazard of the Queen Charlotte-Fairweather fault system in northern BC and southern Alaska, discovered significant fluid flow along faults of the system. A mud volcano was newly discovered west of Dixon Entrance, located within the fault zone and straddling the US-Canada border, in what appears to be a large mass-wasting field. This area is poorly surveyed and lacks good bathymetric and geophysical data that is needed to properly study the area. Due to the significance of this find, and its relationship to understanding the seismic hazard and tsunami generating potential of the fault system, better bathymetric data need to be collected. A detailed mulitbeam echoesounder survey of the area would provide detailed images of the mud volcanoes and landslides suspected to exist. This information would increase our understanding of the processes that cause earthquakes along the fault system and provide information useful in the evaluation of potential tsunamis.

The area of concern lies in the path of major shipping, including cruise liners, as well as to the west of the most heavily populated towns of southern Alaska and northern BC; Ketchikan and Prince Rupert. The potential of high volume burst of methane reaching the ocean surface could be of danger to shipping and the potential of major submarine landslides that could generate tsunamis could impact the populated areas to the east. Therefore, it appears urgent that further investigation of the area takes place and that additional geophysical and bathymetric data be collected soon to evaluate the geohazards of the area. The future investigation should be a cooperative US-Canada effort.